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PARASITES

By

GEOFFREY LAPAGE

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PARASITES

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PARASITES

CHAPTER I

DEFINITION OF THE PARASITE

THE following pages will not attempt to give a detailed account of parasites. For that a separate volume would be required, or more than one. We shall be wiser to select from the great mass of facts known about parasites and to emphasise those which best illustrate the main principles of *Parasitology*. We have to try to understand the way of life called *Parasitism*, a way of life which has been adopted, in response to those influences which have determined the evolution of species in general, by many animals and some plants. We also have to study the effects of this way of living, both upon the parasites themselves and upon those other animals and plants upon which the parasites prey and which are naïvely called their hosts. We shall learn by doing this something of the great importance of parasitology to man, not only because he is himself the host of many parasites, some of which cause in him serious disease, but also because his domesticated animals and crops and food supplies and manufactured goods and buildings and other works of his hand are damaged by them.

But before we can understand properly the parasite's way of living, we must first very briefly inquire how life maintains itself upon the earth. How it arose in the beginning of things we do not know. All we can say with honesty is that life seems to have

originated from some kind of dead elementary protein that acquired the power of movement, of feeding itself upon simple chemical stuffs which perhaps were allied to itself, of growth, of sensitivity to external influences and the power to adapt itself to these incessant stimuli from its environment. Most important to its subsequent evolution, it also acquired the ability to reproduce its kind and to pass on to its offspring something of its own nature.

From such elementary life all the living things of to-day are descended; and at a very early stage in their development two methods of feeding were distinguished. One of these was practised by the creatures which gave origin to all the plants, the other by those from which the animals have been derived. The difference between them can be broadly summarised.

The plants have retained the power, theoretically ascribed also to the earliest living jelly, of feeding upon simple chemical compounds. They possess a green pigment called chlorophyll, or other pigments allied to it (see *An Introduction to Biology* in this series), which enable them to split up the carbon dioxide of the air in the presence of sunlight, the carbon being retained and built up into sugars and starches, the oxygen being set free. They can also take the nitrogen they need for building up the proteins of their protoplasm from such simple compounds as the nitrates in solution in water, and some of them can even utilise the nitrogen of the air.

Along another line developed organisms which have no chlorophyll or allied pigment. They could not, therefore, perform these remarkable feats. These are the animals. They cannot assimilate carbon in a form less complex than such carbohydrates as the sugars and starches or hydrocarbons like the fats; nitrogen they must obtain in the relatively complex form of proteins. All these substances must be split up into simpler compounds before they can be used in their

bodies, and this is done by ferments made by the animals themselves. To carry out this relatively elaborate process the animals need a digestive system. Since the proteins and carbohydrates and fats are only to be found in the bodies of other animals or plants, these must be sought out, chased and perhaps fought before they can be consumed. The animal, therefore, needs also locomotor organs and weapons of offence and defence, as well as muscles to move it about and a nervous system to relate the whole animal as a unit to its surroundings and to control its activities. The plant need not move about from place to place, nor does it require a digestive tract or a nervous system. To this fundamental difference in the mode of feeding, therefore, a great many of the differences between the plants and animals can be traced. The plant's way of feeding is called holophytic, the animal's holozoic; and although there are some plants like the pitcher plant and the sundew, which feed like animals, catching live insects and secreting ferments which digest them, and some animals, especially among the primitive ones, which, like *Euglena,* for instance, contain chlorophyll, and can live either holozoically or holophytically, the general distinction does hold true and those exceptions which occur prove the rule.

All living things, however, are not either holophytic or holozoic. Some there are, both animals and plants, which live in the juices of other animals and plants that are dead and decaying. Lying there in a bath of dead liquid organic matter, they absorb it directly through their permeable skins and use it as food. Such creatures are said to be saprobiotic; and if they belong to the animal series they are called saprozoic, if to the plant series, saprophytic. Many parasites are saprobiotic in the juices of their living hosts, and some of them have arisen from true saprozoites and saprophytes that live in dead liquid organic matter in the outer world.

In our ponds and ditches, for example, where vegetable matter is decaying, we find those minute lowly lumps of primitive jelly called amœbæ. Living in the intestine of frogs that delight in such ponds, we find other amœbæ; and we may suppose that these have been derived from ancestors which once lived, ages ago, a free life in the pond. But some of them entered the frog either through its mouth or through its vent and, slowly becoming accustomed to life in the intestine, finally adopted that way of living. Probably *Entamœba coli,* which lives in the intestine of almost every human being alive, arrived there in a similar way, long ages ago, when the ancestors of man were less fastidious about contact with decay and putrefaction than most modern men are.

Neither *Entamœba coli* nor the amœbæ in the frog's intestine is strictly a parasite, but they indicate without doubt one way in which the parasitic habit may arise. They are instances of the kind of association between animals, or between animals and plants, that is called symbiosis, a term which means association for mutual benefit. Another example of it is the little tubular green *Hydra* with its circlet of tentacles, that lives in our freshwater ponds and streams. At first sight this creature seems to be a contradiction of the distinction given above between the animals and plants. It gobbles water-fleas by the dozen and is obviously an animal; yet its tubular body and tentacles are full of the green chlorophyll that is characteristic of the plant. Careful examination alone provides the explanation; for it shows that the chlorophyll belongs, not to the animal *Hydra,* but to minute plants that live inside it. There are two creatures here, an animal and a plant, and their association is for mutual benefit. The oxygen set free by the plant and the starch that it makes are used as food by the *Hydra;* and the nitrogen cast off as waste matter by the animal is used by the plant. A more familiar instance of symbiosis is the lichen, an asso-

ciation between two plants, an alga and a fungus. More striking still, perhaps, is the partnership between the crab *Melia* and the sea-anemone, which it carries about in its claws and which it uses as a weapon and food-getter.

Symbiosis must be distinguished from another kind of association in which one creature lives at the expense of another less intimately, but gives nothing in exchange for the benefit it receives. On the other hand it does no harm. Such associations are called instances of commensalism, and the habit of the sea-anemone *Adamsia palliata* of living on the borrowed shell of the hermit crab *Eupagurus prideauxi* is an example of it.

Such associations help us to understand the parasite, because parasitism is only one more example of the way in which two or more living things may live together. We have only to imagine an instance of commensalism in which one partner not only does not benefit the other, but actually does it harm, and we have almost a definition of true parasitism. Damage—that is the essential feature of the parasite. It harms its associate, and by that harm is distinguished from both the commensal and the symbiont.

That this is still not quite the whole truth about the parasite we shall realise if we consider for a moment that type of the individualist, the carnivore. Consider the man-eating tiger for example, roving abroad, bloodblind, preying upon all flesh. Not a whit less individualistic, though to the human mind less impressive, is the ungulate, the wild antelope, the bison or the giraffe, which preys no less, but whose appetite is for the vegetable world. Both are adventurers, obedient without the capacity for reason, to that primitive philosophy—primitive at least as we human beings see it—which eschews altruism and to which Nature has been faithful from the beginning; and with them stand countless rovers and robbers belonging to every

group of the animal kingdom. In the water these predators range from that marvellous swimmer the cormorant to those aquatic terrors the larvæ of dragonflies which help us by feeding on the young stages of malaria-carrying mosquitoes and of gnats; on the land, from the great cats like the jaguar and the lion to the carnivorous slug *Testacella,* the so-called Gardener's Friend, which is so easily distinguished from all other slugs by the little shell it carries on the end of its tail. Many other predators there are which may be useful to man. Some of them are described in *Insects,* in this series.

A fascinating volume could be written about such rovers and robbers, for all of them show that striking beauty of swift movement and almost incredible efficiency of response and co-ordination of complicated muscular action which is their mark and the imperious condition of their success. But their immediate interest for us is the fact that it is not a far cry from them to some forms of the parasite. The human ironist, taking the no less human "hanger-on" as his sample of the parasite, may remark that such social pests are only less courageous or more sophisticated than the brigand; and we shall not find it any easier to mark the animal parasite sharply off from the predator. The only distinction that we can draw between them is the rule that the parasite is generally smaller and weaker than its prey, while the predator is usually bigger and stronger.

We have thus as complete a definition of the parasite as the present state of our knowledge allows us to make. It is admittedly vague; and the difficulty we find in distinguishing more clearly between the parasite and on the one hand the predator, on the other the commensal, the symbiont, and the saprobiotic creature, is an excellent example of the ever-present and capital difficulty of the biologist. He deals with things that are alive, and whatever lives is in a state

of constant change. He cannot, therefore, expect to satisfy that human desire, derived we know not whence but certainly a widespread plague, to ticket all things and put them neatly into separate compartments. Nature abhors such rigid categories. She works by slow changes that leave in their train innumerable connecting links between whatever units are distinguishable in the protean web of life. She presents us, for example, with parasites derived from a predatory ancestor; others she shows us descended from the symbiont or the commensal; and as if the connecting links between these and the parasite were not enough to confuse us, she shows us also parasites whose ancestors were either saprophytes or saprozoites. We are forced by the facts, therefore, to be content with the statement that the parasite is an animal or plant which lives either inside or on the surface of the body of another bigger and stronger animal or plant which is called its host, and there does it harm.

CHAPTER II

KINDS OF PARASITES

Both plants and animals may be parasites, but the parasitic plants can be only briefly mentioned here. An adequate description of them would need a separate volume, and a very interesting and important volume it would be. For, as Professor Mangham points out in *An Introduction to Botany* in this series, the losses caused to agriculture by such parasitic plants have been colossal and still are a serious menace. Quite naturally, perhaps, the average man is more interested in the organisms that attack his health or pocket or his food supply than in such parasitic plants as the Mistletoe, the Dodder, or the other plant parasites that do little harm to man. He is interested also in the creatures that work on his side, as some parasitic plants do. The fungus *Empusa,* for example, attacks and helps to keep within bounds that dangerous plague, the common house-fly; and there are others.

But among the plants there is, of course, one group of microscopic organisms whose importance to man is incalculable, for they not only help him, but can cause very serious diseases in him and his allies. This group, called the Bacteria, familiarly known as microbes, or germs, and including the rod-shaped bacillus, the globular coccus, the twisted spirillum, and others, may be regarded as a group of lowly organisms which have not developed far beyond the primitive jelly, or we may look upon them as very lowly plants that have developed along a line of their own and have evolved a particular mode of parasitism. Allied to them are the *Spirochætes,* of which the organism which causes syphilis is an example; we cannot say yet whether the

so-called "filter-passers" and "ultra-microscopic viruses," about which we hear nowadays so much, but which we understand so little, are organisms at all.

All such plant parasites, because of their minute size, their phenomenal powers of increasing their numbers with extraordinary rapidity, their resistance to adverse influences of all kinds, and the ease with which they can be transported in great numbers by the air, by water, or by the bodies of man and of animals, are among the most formidable enemies of other living things. The study of them forms a separate and difficult branch of biology called Bacteriology, and a separate volume would be required for an account of this. We can say no more about them, but must concentrate our attention on the animal parasites.

If we do this we shall find it possible at the outset to divide animal parasites into two groups according to their position either inside their host or upon its surface. Those which, like the threadworm *Enterobius* (Oxyuris), so common in children, live inside their host's body, are called *Endoparasites;* those which, like the louse of man or the cattle tick that transmits from cow to cow red-water fever in England and on the Continent and especially in tropical countries, are called *Ectoparasites.*

The fact that some parasites may spend the whole or the greater part of their lives either on or inside a host suggests another kind of grouping. Parasites may be *permanent,* such as the Trypanosome, which has lost entirely the power of living outside the body of a host; or *temporary,* like the leech, which sucks the blood of other animals but also lives a free life in fresh water or in the sea. Permanent parasites are usually more altered by their parasitism than the temporary ones are, and intermediate grades of modification occur which connect these two as they connect all biological categories. The temporary parasite has also been called a *periodical* parasite, a name which draws attention to

the fact that its parasitism is, so to speak, an episode in its career, although it is an experience which regularly recurs and which it must encounter for a certain period. At those periods of its life when it is not parasitic it can live as other free-living animals do.

This parasitic phase may be the fate of the young creature only, as it is of the caterpillars of numerous insects of the group to which the ants and wasps belong. *Œstrus ovis,* the sheep nasal fly, is another instance, its caterpillar stage alone being parasitic in the nasal cavities of sheep, causing serious disease there, the chrysalis and mature insect both living in the world outside. More remarkable, because it occurs in a group which shows very few parasites, is the *Glochidium* larva of the common fresh-water or swan mussel of our ponds and streams, *Anodonta cygnea.* The young of this animal grow up between the lamellæ of the gills of the parent until they have a bivalve shell provided with hooklets on its inner faces, a muscle to open and shut this shell, and threads like the so-called "beard" which attaches the sea mussel to rocks and piers.

These young have no alimentary canal and they cannot live independently. They must trust to chance to send near to them certain fish whose approach stimulates to activity the muscle operating the shell, the two halves of which are then rapidly opened and shut. This violent clapping of the valves drives out the threads of the "beard" and again all depends on the chance that either these or some part of the shell will touch the fish. If this does occur, the two halves of the shell snap shut, the hooklets are buried in the fish's skin or gills or other external soft part and, irritating it, cause a growth of tissues round the glochidium larva, which thus becomes enclosed and may live on the juices of the fish for two to six weeks while the organs of the adult stage are developed. The whole process has been interpreted as a device to ensure that

the offspring of the slow-moving mussel may be disseminated by the active fish over much wider areas than would otherwise be possible, and is contrasted with the other method of achieving the same object by an active free-swimming larva; but it also exposes the species to considerable risk that a high proportion of its young may not survive at all, and in this respect may be compared with the similar risks encountered by the parasites discussed in Chapters VII. and VIII.

The human embryo, living inside its mother's womb, is, strictly speaking, another example of this temporary parasitism of the young phase of the species. That it is a true parasite is undoubted, for it is dependent entirely for food on its mother, and by taking food from her does her considerable damage. The fact that this damage is counted normal and necessary by us, because, like other animals, we obey a deep-seated urge to propagate our species, is apt to make us forget that the damage done amounts to quite as much as that effected by some other parasites; and if anything goes wrong with the growth of the embryo, we know that it quickly may destroy the mother altogether. There could be no better instance, in fact, of a temporary but obligatory parasite than the human embryo.

Other temporary parasites are parasitic when they are sexually mature, the young stages being free-living. Of this there are many instances. The young stage of *Ancylostoma,* the human hookworm, for example, is saprozoic in the soil, and this larva enters man to become sexually mature in his body. Under this heading, too, we must place many creatures which, like the gnats and mosquitoes and the fleas, are ectoparasites and very transient in their parasitism, although their brief attention to man at least may suffice to inoculate into him fatal poisons. We approach here once more to the vague border-line between the parasite—and especially the temporary parasite—and the predator. For obviously all the predators, which, like

the birds and mammals and beetles and other creatures which raid our crops, or even the clothes moths and furniture beetles and booklice and others which attack our household gods, are not far removed from the temporary parasites.

Yet other periodical or temporary parasites are parasitic throughout their lives. Of this a good example is the common cattle tick, *Ixodes ricinus,* which carries red-water fever from beast to beast. From the eggs laid by the adult female of this species a six-legged young stage emerges. This larva has no wings, but lying in the grass it comes into contact sooner or later with a cow and crawls up on to its skin. Piercing the skin with the stylets in its mouth, it sucks blood until it is gorged. It then drops off on to grass, ceasing to be parasitic. A period of free life follows, during which it grows, sheds its skin, and assumes a new one. It is now called a nymph and has eight legs. This nymph attacks another beast and sucks more blood, becoming parasitic thus for another spell. When gorged it drops off once more and moults again. The final stage is the adult tick, and this again becomes parasitic for a longer period. The tick, therefore, is a good example of a temporary or periodical ectoparasite: and the fact that it must be parasitic if it is to complete its life history introduces us to another category.

If the Cattle Tick found no opportunity of sucking blood it would die. It is, therefore, what is called an *obligatory* parasite, and it must be distinguished from such a temporary parasite as, say, the maggot of the blowfly when it enters foul wounds or sores on a human or animal body and develops there. Normally it is not parasitic in such positions, but develops wherever the eggs are laid, in decaying organic matter of almost any kind. The fact that it can be truly parasitic if the eggs are laid upon the sores of living animals makes it a *facultative* parasite: the fact that it can, and in this instance usually does, develop else-

where, distinguishes it from the obligatory parasites which must at some stage be parasitic or die.

These facultative parasites are interesting because a great many of them are saprobiotic in free life. Many roundworms, for example, live in the soil so long as food is abundant there; but when the food supply fails or grows slender, they can enter animals or plants and live in them. The roundworm, *Leptodera appendiculata,* for example, lives normally in damp earth, but it can become parasitic on the slug *Arion empiricorum,* and when it does so it grows larger, loses it mouth, and produces more eggs. These, as we shall see, are normal results of parasitism, but, in this particular instance, before the worm can become sexually mature it must resume its free life. We can therefore say that it is not yet fully established as a parasite. It is a good example of what the great French parasitologist Brumpt has called *inchoate* parasitism, and shows us a species which may, in effect, be actually slowly abandoning free life for parasitism before our eyes. It is probably the adaptation of such creatures to the saprobiotic life that makes it so easy for them to change temporarily to the parasitic way of living, for after all the change is relatively slight. It is in essence a change from life in one kind of dissolved organic matter to a similar mode of life in another. But the importance of such a possible change is obvious. If such a saprobiotic creature loses the power it once had of going back to the saprobiotic mode of life in dead organic matter it becomes an obligatory parasite.

If we like to multiply distinctions further we can establish a category of *accidental* (or incidental) parasites to include all those creatures which live usually a free life but are only occasionally found living parasitically in or on another animal's body. Some of the *Myriapoda* (the group which includes the Centipedes and Millipedes), for example, can live for several days in the human body.

Some other parasites normally occur in only one species of host, but may now and then live in other species. These also have been called *accidental* parasites. The worm *Echinorhynchus gigas*, for example, is normally found in the pig, but may occur in man occasionally; the common liver flukes *Fasciola hepatica* and *Dicrocœlium lanceolatum* found in sheep and other mammals, may occur in man; while the broad tapeworm of man, *Dibothriocephalus latus*, characteristically parasitic in him, may be also found in the dog, the cat, and the fox.

Two other categories of parasites remain to be considered. The first of these have been called *hyperparasites* or auxiliary parasites, and they illustrate the much-quoted rhyme:

> "The little fleas have lesser fleas
> Upon their backs to bite 'em,
> And the lesser fleas have other fleas,
> And so—ad infinitum."

"Ad infinitum" expresses, we must confess, poetic licence rather than the truth; but it is true enough that parasites are themselves attacked by other parasites, and instances are known of yet a third parasite of the parasite of a parasite.

This fact has been utilised by those whose business it is to rid our crops of the animal scourges which attack them, but, although some of the parasites that cause disease in man may also suffer from parasites, it has not yet been possible to try to control these latter in the same way. As Professor Balfour Browne points out, moreover, in *Insects* in this series, we must, if we try to control any agricultural pest by encouraging the multiplication of the parasites that attack it, take care that the parasite itself does not become a worse scourge than the original pest. The practice of such a method is, furthermore, always a difficult matter. For to be successful with it we must be sure that we are able to

rear these hyperparasites in sufficient numbers, that they are not likely to lay their eggs on other hosts which may be equally favourable to them and so may absorb all the parasites and let the creature we are hoping to exterminate go free, that there is a host on which our helper can live at those periods when the enemy is absent, that our helper has greater fecundity than that of the enemy, that its cycle of development is quicker, that it is less sensitive to climatic influences than its host, and that it is free from parasites itself.

These conditions are not easily fulfilled, and this form of biological attack is therefore far less readily launched than might be expected. Nevertheless, it is being actively exploited to some purpose. There is a station at Farnham Royal, Bucks, from which such insect helpers of man are exported to our colonies, where they can be of great value; and other countries have similar stations.

One other use of the parasite in a similar way is worth noting. It has been found that people suffering from the disease called General Paralysis of the Insane sometimes benefit if the parasite that causes malaria is introduced into their blood. How this beneficial influence is exerted cannot be explained here, but it is another instance of the fact that one parasite may help to neutralise the harmful effects of another.

Finally, there is the category of the so-called *pseudo-parasites,* against which the parasitologist must always be on his guard. The doctor especially needs to be familiar with these, for again and again he encounters, in the urine and fæces and other excreta and in the juices of his patients, animals and plants which may or may not be agents of disease. He has to decide whether these are real parasites of his patient, or whether they have been merely accidentally introduced into the body or have got into the material he is examining after it left the body. In the alimentary tract, for example, numbers of protozoa and eggs of

worms and even the caterpillars and chrysalids and eggs of insects may be found which have been introduced with the food and drink. They are merely passengers there and have no effect on the patient. Introduced by the mouth, they are either destroyed by the digestive juices or resist them and pass out again and resume their normal development in the world outside. Some of them may have got into the fæces and urine after these have left the body. Adult insects and their grubs may, for example, be attracted by the odour of these and may either feed upon them or deposit their eggs in them. The detritus of vegetable matter, the various forms assumed by partially digested food, animal and vegetable matter that may have fallen into the fæces or urine from the air itself, or shreds and threads of garments or other fabrics, may all lead to errors of diagnosis, especially because some of them are, to the inexperienced observer, extremely like the true parasites of man. This kind of difficulty is enormously increased when an animal is being examined, because the chances of contamination of its food, drink, or excreta are very much greater.

CHAPTER III

DISTRIBUTION OF PARASITES

A. Zoological

Because the parasite is smaller and weaker than its host and because, as we shall learn in the next chapter, the adoption of the parasitic mode of life involves profound changes in the parasite's structure and physiological processes, we should not expect to find that many of the backboned animals have become parasites. For they are, speaking generally, the largest of animals. Their bulk, their relatively heavy and resistant skeletons, and the complex structure of their bodies, must all have worked against success in parasitic life. They were, moreover, the last members of the animal series to appear and have therefore had less time in which to adapt themselves to such a mode of life. More potent reason still, they are more efficiently equipped for the battle of life than any other kind of animal, and have actually been more successful, unless we count the ubiquitous insects as their equals in this respect. This very success, proved as it is on the land, in the air and under the water, may have determined the fact that they have so little explored the possibilities of parasitism.

There are, however, one or two interesting vertebrate parasites. With the exception of the few species of bloodsucking bats, of which *Desmodus rufus* is an example—the so-called "vampire" not sucking blood at all—vertebrate parasites belong, it is worth noting, to the lowest section of that series, the fishes, and two of them to the group called the *Cyclostomes* or round-mouthed fishes, which stands at the very root of the

vertebrate stem. These two are *Myxine,* the hagfish, and *Petromyzon,* the lamprey. The hagfish is the more formidable, for it not only, like the lamprey, inflicts grave wounds on other fish and aquatic creatures by rasping off their skin and flesh with the horny teeth inside its suctorial jawless mouth and on its pistonlike tongue, but by means of these teeth and its tongue it can also bore deeply into the muscles of its host, burying its head and the fore-part of its body in them. In order that it may breathe while in this position, the inlet of the water of respiration is not by the mouth, but through two small pipes which lead to the gullet from two small holes far back on each side of its eel-like body, and this water, after passing over the tufts of bloodvessels in the gill pouches on either side, finds its way out again by tubes which lead to the same pair of holes. The fish's method of breathing by the intake of water through the mouth and its passage over gills and out again by several separate gill-slits, has thus been modified by the parasitic habit of this creature.

If, however, the vertebrates show us very few real parasites, the very reasons given above for their failure to explore this mode of life—namely, their large size and the complexity of their organisation and the high degree to which its control and co-ordination have been brought—make them very successful predators and robbers. They all are, moreover, in a sense, parasitic on the vegetable world, for, like every other animal, they depend for their existence, at one or more removes, upon plant life. But their main interest to the parasitologist is that they provide the food and dwellings of parasites rather than examples of parasitism itself. They are the hosts, *par excellence,* and very few of them have escaped the attention of one or more uninvited guests.

Three other great groups, or phyla, of the animal kingdom show us, like the vertebrata, very few parasites. These are the *Cœlenterata,* a group which

includes the sea anemones and corals and their like, and among which we find many sedentary animals but few real parasites; the *Echinodermata,* comprising the starfishes, sea-urchins, sea-cucumbers, and similar species; and thirdly, the *Mollusca,* often miscalled the shellfish, in which group occur many creatures which, like the piddock (*Pholas*) and the shipworm (*Teredo*), bore into rocks or ships and piers and other marine works of man, but which cannot for this reason be called parasites. Other shellfish approach near to parasitism through the habit of commensalism, and some of them, like the young stage of the freshwater mussel already mentioned, are really parasitic. Others are usually parasitic upon the bodies of *Echinodermata.* They may be either ectoparasitic like the comparatively unaltered *Thyca,* which lives on the bodies of members of the starfish group, or they may be endoparasitic, and are then much more altered by their parasitic life.

Three other big groups of the animal kingdom remain, and to these most of the parasites belong. These groups are the *Protozoa,* the earliest group to appear in evolutionary history, the rather loose collection of creatures which some writers call the *Vermes,* or worms, and the most highly organised of the backboneless animals, the *Arthropoda,* or creatures with jointed limbs. Let us look at these briefly in turn, beginning with the worms.

The animals that used to be grouped under the general term Vermes, or worms, are now subdivided into several groups. The types of them most familiar perhaps are the earthworm, the lugworm of our shores, the leech, and the tapeworm. The parasitologist is not concerned with the groups to which the lugworm and the earthworm belong. The leeches are external bloodsucking parasites of man and other animals. They are able to make within their bodies a fluid which they squirt into their victim's blood, and

which prevents the clotting of its blood, so that their meal is assured; and the part they play in the transmission of disease will be referred to below. Most of the other worm parasites belong either to groups known as the *Nematoda* or Roundworms or to the *Platyhelmia* or Flatworms, the English names of which refer to the characteristic shape of the body in each group; and all of these have progressed in parasitism further than other parasites have.

Among the flatworms, however, we find a section called the *Turbellaria,* or Eddyworms, which are not parasitic, though many of them are carnivorous and must be counted among the most terrible of the smaller freshwater and marine predators. They interest the zoologist because it is probably from creatures like them that the other flatworms, the flukes and the tapeworms, have been derived. Let us be clear about this. It is not suggested that a modern tapeworm or fluke arose from a modern free-living eddyworm, or even that such a direct transition as this occurred in the past. The suggestion is rather that all the flukes and tapeworms probably arose from the ancestors of the modern eddyworms, a hypothesis which can be expressed, as can all evolutionary descent, better by comparison with a system of rivers than by the familiar and often misleading form of the branching genealogical tree. For rivers are often difficult to trace to their sources from other streams, or from the subterranean waters. They may pass underground and appear to arise anew; and we have to dig long and patiently to find their origin. So with animal groups. We are still digging, for example, for the source of the vertebrate river, for the origin of the sluggish molluscan canal and for the exact point in the ancient marsh of early organisms from which began the twin streams that we call animal and plant.

Somewhere near this point began, we must believe, a fascinating series of creatures which we call the

Protozoa, most of which are microscopic in size and very difficult to study. They may be parasitic on the surface of animals, but the majority of the harmful ones are endoparasitic. Malaria, sleeping sickness (but not "sleepy sickness," which is caused by one of the bacteria), the oriental diseases kala-azar and tropical ulcer, amœbic dysentery, and red-water fever of cattle, are only some of the serious diseases due to them. It can be truthfully said that the comparatively new branch of zoology called Protozoology presents the most difficult and intricate and perhaps for that reason the most fascinating of all problems for the modern biologist. We shall see in subsequent chapters how closely it is bound up with the study of the parasitic members of the third great phylum of animals that includes great numbers of parasites, the *Arthropoda.*

This enormous group, including as it does the crustacea, to which section such creatures as the crab, the lobster and such parasites as the whale-lice belong, the centipedes and millipedes, the spiders and scorpions, and the great series of insects, is of great importance to the parasitologist. To the economic parasitologist, he who studies parasites as they affect man himself and all his creatures, this group will seem of great importance because members of it transmit other parasites from host to host and spread them thus about the earth; but he has to deal also with those other members of it who are active parasites themselves, either on the surface of or inside both man and his domesticated animals, or as enemies of the farmer.

B. Distribution in the Host

No animal is free from parasites, and no tissue of the body escapes them, although some animals, and some tissues and organs, are more liable to attack. The vertebrates, for example, suffer more than the

backboneless creatures do, and certain organs, such as the skin, and notably the alimentary tract and appendages of it like the liver, being more accessible to potential parasites living in the outside world, are often the first organs to be attacked. Once established in such situations, the parasite may not spread to other organs; but many parasites that began in the alimentary tract especially, have extended their habitat, and either journey for periods through the body tissues, returning "home," as it were, to the intestine, or leave it entirely to take up their abode in the deeper tissues.

That animals are not the only hosts of parasites we have already learnt. Plants also are attacked, and the serious damage done to wheat and other cereals, to beet and various bulbs, by the roundworms that we call "eelworms" of various kinds, brings home to us the fact that many organisms living in the soil can leave it to damage our crops. They may also harm our animals and even ourselves.

The *geographical distribution* of parasites corresponds, of course, to that of the hosts in which the parasites live. We have space to do no more here than to draw attention to the fact that all parasites are more abundant, as is all plant and animal life in general, in the tropics. We shall learn also, in a later chapter, that many parasites depend absolutely for the completion of their life histories upon a second host which transmits them from the vertebrate in which they live to another individual of the same species; and in this second host, which is usually a bloodsucking insect or other invertebrate, part of their life cycle must be passed. This means that the distribution of such parasites will correspond exactly to that of the second host without which they cannot continue to live; and this fact may have great practical importance. The trypanosome, for example, which causes sleeping sickness in man in Africa, depends entirely on the tsetse fly, in which alone it can pass a part of its life history. We

can be sure, therefore, that where that tsetse fly does not exist, that form of sleeping sickness will not trouble us either. The same is true of malaria, of the red-water fever of cattle transmitted by ticks, of some of the diseases caused by tapeworms and flukes and of other maladies.

The distribution of parasites in *time* is largely a matter of conjecture. Their particular mode of life means that the hard parts which are most often preserved as fossils are lost before the parasitic life can be successful. What parasites, for example, infested the great intestines and other organs of the giant reptiles that once lived on the earth and in the air and water, we do not know. It is conceivable that such parasites played some part in the overthrow of this enormous race. The bacteria certainly must have been myriad Davids to threaten incessantly these Goliaths. We cannot ascribe to them all the power which H. G. Wells allows them when he makes them the only earthly power that could kill his men from Mars, but, in common with other parasites, they must have been a factor in the downfall of every race that is now extinct.

CHAPTER IV

EFFECTS OF PARASITES UPON THEIR HOSTS

Several factors determine the nature and extent of the damage done by a parasite. Its *position* in the host's body may influence what we call its pathogenicity or capacity for doing harm. This position will not necessarily depend upon the way the parasite enters the host. It may enter passively, without effort of its own, being carried to the host by the air, or in the food or drink, by the sexual act, or by the bites of bloodsucking ectoparasites, or even by the blood of the host which takes it to the egg or embryo while this is still in the parent, so that the young are born with the parasite already in them. Or it may enter by an active effort of its own, as when the young of the miner's hookworm penetrate the skin of man, or the miracidium larva of the liver fluke bores its way into the snail *Limnæa truncatula* (see Chapter VIII.).

But the endoparasite, at any rate, rarely remains near the point at which it entered. Usually it migrates or is carried by the blood to other parts, and its position in those parts may help to determine the damage it can do. It may reach a vital organ and settle down in it, as when the egg of the tapeworm Tænia cœnurus of the dog is eaten by a sheep and grows into a bladderworm which settles in the brain or spinal cord of a sheep and causes the disease called staggers or gid, the symptoms of which are due chiefly to the pressure exerted by the bladderworm on the brain. This pressure causes disturbances of co-ordination of movement such as a staggering gait, a frenzied careering about a field in circles towards that side of

the brain on which the bladderworm lies, or the turning of somersaults. Particular symptoms are also caused according to the position of the parasite in a particular part of any organ it may inhabit. If the bladderworm that causes gid settles in the front end of the brain it will not do so much harm as if it settles farther back in the part of the brain that contains vital centres of nervous activity such as those which control the heart's action or the breathing. If it settles in the spinal cord alone, it will cause paralyses and spasms of those parts only which are controlled by that section of the spinal cord which it inhabits.

The similar bladderworm of the armed tapeworm of man may develop in him as well as in the pig, in which it is normally found, and, if it does so, may reach the eye and cause inflammations and opacity of the lens there, or may settle in the brain and cause headaches and cerebral anæmia due to its pressure upon the arteries that supply the brain with blood, or distension of the brain with fluid (hydrocephaly). By the irritation of the nervous tissue it may, like the parasite of gid, cause epileptiform attacks, and it may also settle in the heart muscle, when fainting fits and attacks of shortness of breath result. People who, by eating pork containing these bladderworms, acquire this tapeworm should be very careful, therefore, that they do not in any way swallow the eggs of such worms with their food or drink and so infect themselves with the bladderworms as well. Fortunately in this country the habit of cooking pork thoroughly and the very efficient inspection of meat carried out everywhere reduce very greatly our liability to this form of disease.

Such bladderworms as these are good examples of the way in which the position of a parasite may determine the damage done, because although the ingestion of tapeworm eggs means usually that numbers of these bladderworms may be disseminated throughout the

body, only those which settle in vital organs cause disease. All those which settle in the muscles, for example, are normally enclosed, by a reaction of the connective tissue that lies between the muscle fibres, in a protective case of this tissue and remain there comparatively harmless.

Some internal parasites, however, habitually attack certain tissues only. The roundworms generally live in the small intestine near to the stomach, into which they may also penetrate. One of them, *Strongylus gigas,* attacks the kidney. Another, *Syngamus tracheälis,* the worm that causes gapes in poultry, settles in the windpipe, while the worms that cause husk in cattle and sheep also live in the lungs and air tubes. *Trichinella spiralis,* another roundworm, occurs in the voluntary muscles, and is found in greater numbers in the muscles of the midriff, those between the ribs and those of the throat and neck.

Some endoparasites attack the blood especially, either swallowing it, as do some roundworms, the fluke and the leeches and other bloodsucking ectoparasites, after they have broken a way into the blood-vessels either with their teeth or with piercing mouth-parts, or, like the roundworms of the genus *Filaria* and the *Trypanosomes,* living in the blood as in a bath and absorbing it as food. Others, such as the parasites that cause malaria, consume the substance of the cells of the blood.

Endoparasites may also feed upon protoplasm itself. The protozoan parasites that cause a form of white diarrhœa in poultry and cattle consume, for example, the cells that line the intestine; others, like *Entamœba histolytica,* the cause of amœbic dysentery in man, make for themselves a ferment which dissolves the lining of the intestine into a kind of soup, in a bath of which the parasite lives and which it absorbs as food. This habit of some parasites of feeding on an exudate provoked by their own damage is an interesting one. It is

paralleled by the human idea of scarring a gum tree to get the resin that exudes from the wound. The mite, *Psoroptes,* which causes the disease of sheep called scab, feeds thus upon the blood serum exuding from the bites it makes; and the grub of the warble fly, which can be such a serious pest of English cattle, causes, beneath the skin of the back of the beast, offensive sores full of matter in which the maggots find their nutriment.

One is almost tempted, in the light of such instances as these, to say that a parasite "selects" its habitation and seems to work with a purpose, but we are not justified in introducing such human conceptions as purpose and choice into interpretations of animal behaviour. All that we know about the behaviour of other animals teaches us that such apparent selections may be merely the result of chemical attractions exerted by the tissues upon the parasite.

The movements of parasites must in themselves be considered as possible causes of injury. The rheumatoid pains and fever due to the presence in man of the roundworm *Trichinella spiralis,* taken in by eating uncooked pork infected with it, are caused by the mass migration of numbers of the young of these worms from the intestine to the muscles. Once they have settled down in the muscles the symptoms cease and the parasites not only do no further harm, but usually are encased, as other foreign bodies often are, by a wall of connective tissue formed by the host, in which chalky matter may be deposited later and in which the parasite eventually dies. The eggs of the fluke *Schistosoma* (*Bilharzia*), which causes a serious disease of the urinary organs in man in the tropics, are provided with spines, the irritation of which produces inflammation of the bladder and of the end of the digestive tract characteristic of this malady, for they work their way out of the tissues in which they are laid into these natural outlets to the outer world where the young

stages of the parasite must seek the snail, inside which they must live for a while.

If for any reason the complicated journeys often undertaken by parasites are not completed, as when, for example, the young of the roundworm *Ascaris* are carried by the blood to the liver and remain there or do not pass beyond the lung, they may cause irritation or disease wherever they settle.

Most of the instances so far cited might be included under the heading of mechanical damage or irritation. With them we should include the bites of fleas, lice, mosquitoes, bed bugs, ticks, leeches, and such other temporary ectoparasites as the bloodsucking bats.

Many parasites, however, obtain their food without doing much mechanical damage to their hosts. Such are creatures like the parasitic crustacea mentioned in Chapter V., the rootlike processes of whose bodies may branch and ramify throughout their hosts without doing to them vital harm. Indeed, they may often avoid, as do the "roots" of *Sacculina,* for example, vital organs like the heart and gills of the crab it lives on, although they penetrate into every other part. The effect of this particular parasite is extremely remarkable, for the female crabs are little altered, but the males acquire the secondary sexual characters of the female, so that they resemble them externally, undergoing what is called "parasitic castration."

Among such general effects we must also include the harm done by the tapeworms, whose suckers and hooklets do little harm in themselves. The damage done by these parasites is due to the fact that they can steal the host's food to such an extent that wasting and ill-health result. This effect may be more serious if the host is young or very old, a factor which is important whatever the method of damage employed by the parasite. The importance of the age of the host is obvious when we learn that not the least damage a parasite may do is to lower the general health of its host to

such an extent that it is predisposed to other diseases. Certain poisonous substances, or toxins, may also be produced by some parasites. The trypanosomes, for example, may set free such poisons into the blood; and although much doubt has recently been cast on statements about the power of these poisons, the existence of many of which has been denied, they certainly must be reckoned among the ways in which a parasite may damage its host. Against them the host produces antitoxins, which may confer upon it a passive immunity.

The secretions made by parasites are an interesting study, but lack of space forbids our entering into it here. It is worth while, however, to record the fact that some of the parasitic worms, and probably other intestinal parasites as well, secrete a substance which prevents the digestive juices of their hosts from digesting them. Thus is answered the question asked by many investigators: Why is not a parasitic worm digested like any other flesh in the gut?

The number of parasites present in any host is obviously another important factor in determining the amount of damage they can do. If a parasite multiplies outside its host, as the liver fluke does, for example, its chances of doing harm are less than if, like the parasite causing malaria, it can multiply within the host's body. Large numbers of a small parasite may cause more harm than a few large ones. Something will depend upon the relative virulence of parasites, and upon the relative virulence of different strains or stocks of them; but the harm done by such microscopic creatures as the trypanosome or the parasite of malaria, which have phenomenal powers of rapid multiplication, generally exceeds that done by such larger endoparasites as the tapeworm. The latter can also reproduce large numbers of offspring; in fact, we shall learn below that it is a feature of parasites in general to be able to do so, but the tapeworms do it more slowly. It is the rapidity of multiplication that

makes creatures like the malaria parasite so harmful. Their capacity for rapid reproduction is only excelled by that of those extraordinarily prolific parasitic plants, the bacteria, and by both it is effected by such non-sexual methods as division of the parent into two or many parts simultaneously produced, this being the phase which usually does the damage.

Growth of the parasite, combined with its existence in large numbers, may be serious in its effects. Thus *Fasciola hepatica* can block up the bile ducts of the liver, the roundworms of the genera *Filaria* and *Strongylus* may block up blood canals and so cause clotting of the blood and swelling and weakening of the walls of the bloodvessels, with the consequent danger that they may burst. Back pressure, too, upon the organs from which the bloodvessels are bringing blood may cause consequent disease in them. Another interesting instance of a disease caused by this obstruction of vital canals by parasites is the Isle of Wight bee disease, due to the blocking of the breathing tubes of the bees by the mite *Acarapis woodii* that is parasitic within them.

Finally, we must not forget that temporary blood-sucking parasites of all kinds damage other animals by the mere fact that they may suck up with each feed blood parasites which they transmit to other individuals. The mosquitoes which thus "carry" malaria from man to man, the tsetse flies which transmit the trypanosomes that cause sleeping sickness, the ticks which pass red-water fever from cow to cow, the sand fly that is being nowadays convicted of transmitting the disease called kala-azar that attacks the Indian and some other tropical peoples—all these are the enemies of vertebrate animals in this respect. The leeches also distribute trypanosomes and other blood parasites among the fishes and other aquatic animals both in fresh water and in the sea. Nor should we forget such creatures as the dog-louse and the dog-flea, which trans-

mit the tapeworm *Dipylidium caninum* of the dog, and may so communicate the worm to children, because the dog may chew up the lice and fleas and then lick the child, and so infect it with the bladder-worm stages that grow up in the child into the tape-worm. The snails which transmit certain stages of the fluke *Schistosoma,* the " water-flea " *Cyclops* and the fish which together transmit the broad tapeworm of man in the Baltic region, and many others of the intermediate hosts described in Chapter VIII., must also be included here.

CHAPTER V

EFFECTS OF PARASITISM UPON THE PARASITE

In an earlier chapter the statement was made that the parasitic life causes characteristic changes in the parasite's structure. It also leads to physiological changes and to the acquisition of new characters. This will be clearer if we consider first the relatively simple instance of an ectoparasite.

On the wool and skin of sheep there is often found in this and other countries a creature called the sheep ked (*Melophagus ovinus*), often miscalled a tick and mistaken for one. Close examination shows, however, that the sheep ked has but six legs, while the tick has eight, and that the body of the ked is divided into head and thorax and abdomen, a feature which, taken with the number of legs, proves it to be an insect, and, not like the tick, a member of the *Arachnida,* the group to which the spiders and scorpions belong.

Yet how different from, say, a dragon-fly or a moth, is this dark brown, loathsome, bloodsucking parasite, with its leathery hairy integument, its long, strong, active legs each ending in strong curved claws. And it has no wings at all. The only traces of them are two disclike vestiges on the skin of its thorax. Remarkable does it seem that this crawling pest can be blood brother to such a beautiful and very active creature as, say, the hover fly, that hangs so marvellously in the sunlit air of our gardens, and, warned by its wonderful eyes and nervous system, darts away at our approach, or the delicate midge, whose activity and high efficiency none of us can deny, or even the

house fly or blue-bottle, that we rightly destroy if we can.

Yet true it is. The sheep ked is a dipterous or two-winged fly, that has been so altered by its parasitic life that it is scarcely recognisable. Instead of the grill-like proboscis by which the house fly gathers up the food which it has liquefied, or the chewing jaws of a beetle, or the coiled sucking tube of a moth or butterfly, its mouthparts are pointed for piercing the skin of its host whose blood it sucks. Its leathery skin is a protective armour. The hairs on its body are all directed backwards so that it can move with the strong clawed legs through the forest of hair in which it lives. Claws help it to cling there when the host, irritated by its bites, seeks to dislodge it; and wings it has lost because it no longer needs them. All its life is parasitic on the sheep. Food is plentiful and need not be sought by active flight. Even the reproductive process is altered to suit the mode of life. For the female ked, when her eggs are impregnated by the male, does not lay them as other insects do. She keeps them in her body till the caterpillar stage is formed, and to this she gives birth. Almost as soon as it is born this caterpillar becomes a hard, dark brownish-red chrysalis or pupa, which either remains in the wool or falls to the ground. Here it is capable of living for six weeks, but usually within about twenty-four days the young ked emerges from it and regains the sheep to begin its life cycle again. Since the female can lay a caterpillar every nine days, the rate of increase is rapid.

Such a parasite illustrates well the general principle that parasitism leads to a simplification of structure in the parasite. This principle is often called "degeneration of the parasite," a phrase which is misleading, because it suggests the human conception of decay, or descent from a "higher" condition to a "lower" one, for which there is no place in

biology. We must try all the time to see things from the parasite's point of view, and if we do this we shall realise that what happens to the parasite is simply what happens to every other living thing when it changes its mode of life. It adapts itself to the new conditions it meets with. No laws of biology are broken, no new ones are brought into being. If the sheep ked loses its wings, or the hagfish its eyes, if tapeworms lose their alimentary canal or liver flukes the cilia that belonged to their ancestors, that need not be degeneration; for degeneration implies loss of efficiency, and no one can accuse these parasites of that. All that happens is a simplification of structure, a simplification that is a stern necessity if the parasite is to succeed in its new mode of life. As the great parasitologist Leuckart said: "Je sesshafter ein Parasit, desto primitiver der Bau"—the more settled a parasite, the more primitive its structure.

The same principle can be illustrated by a thousand examples. All parasites tend to lose locomotor organs, for example. They are no longer needed, and Nature dispenses with them. The process may take a very long time to accomplish; and we find, therefore, various degrees of it in various parasites. The sheep ked and the louse have lost their wings entirely; but both sexes of that close relation of the sheep ked, the horse ked, or New Forest fly, *Hippobosca equina,* retain their wings, although they do not use them as much as they might do, preferring to run between the hairs of the host. It will be interesting for some future biologist to find out whether, generations hence, this horse ked arrives at the wingless state of its near relative, the sheep ked.

More striking examples of this loss of locomotor organs can be found, as would be expected, among the endoparasites, because the entry into the interior of another animal must obviously cause a more profound modification of structure than the mere settle-

ment on its external surface. The power of movement, moreover, is not so important to the endoparasite as it is to the ectoparasite and the free-liver, and the primary stimuli that cause the evolution of the power to move —namely, the need to seek food, to chase and secure it by force, the need to seek a mate and copulate with her, and also the need for self-defence against other animals, or escape from them or from other inimical influences, operate less powerfully upon the endoparasite, because inimical influences inside another animal are less abundant, and hunger and sex can be satisfied with relatively little change of position.

Recent work has, however, shown that even the endoparasite moves about in the body of its host much more extensively than was formerly thought. Some of the parasitic roundworms, especially, can carry out remarkable migrations through the tissues (see Chapter VI.). Even the tapeworm lying in the intestine may execute considerable movements, although there may seem to be little reason why it should do so, because it lives in a bath of food which it takes in through its soft skin. To effect a fertilisation of the eggs in each of the flattened segments of which it is composed, all that is necessary is that the genital pore at the side of each of these should be brought into contact with the genital pore of a neighbouring one. This is done by wrigglings and contractions of the segments themselves. These segments possess, once they are ripe and ready to be discharged from the body, considerable power of movement by similar contractions, especially if the temperature be suitable. One of the characteristic differences, in fact, between the two chief tapeworms of man, *Tænia solium* and *Tænia saginata,* is the sluggishness of the segments of the former, which move comparatively little, and the activity of those of the latter, which may be entirely beyond the host's control, wriggling their way out of his alimentary canal into his bed or underclothing

before they ultimately succumb to the death and disintegration by which the ripe eggs in them are normally set free.

The tapeworm, however, is not a good instance of the loss of locomotor organs due to parasitism, because its ancestors had neither limbs nor wings. Better examples are furnished by the remarkable series of parasitic *Copepoda,* a group of small aquatic crustacea allied to the lobster, the shrimp, and the woodlouse. Among these there is that type of the active, swift, and efficient predator, the creature called *Cyclops,* common in freshwater ponds, often erroneously called the water-flea and conspicuous as a rule by the presence beside its long tail of a pair of bags of brightly-coloured eggs. The activity, and lightning response to stimuli, and co-ordination of movements shown by this creature are remarkable. It might fairly be described as a small epitome of the qualities required for success in the struggle for existence under the water.

Related to it, however, is the family *Caligidæ,* similar small creatures which have adopted a parasitic life upon the skin of fishes, whose blood they suck. Since they are ectoparasites, we shall not expect to find them very much modified, and this is so. They have kept, at least, the power of swimming freely. Another family, the *Lernæidæ,* have, however, been more modified. These are ectoparasites also, the young ones living usually on the gills of fishes of the plaice family, the female alone of the adult stage upon the gills of fishes of the group to which the cod belongs, into which she burrows, holding on by rootlike processes of her head; but her swimming feet have now become mere vestiges. The *Chondracanthidæ* and *Lernæopodidæ* show similar modification, but the male is swept into the change, becoming much smaller than the female and also permanently parasitic upon her. Most modified of all are species like *Rhizorhina,* parasitic upon the group of seaworms to which the lug-

worm belongs, and on certain of its own relatives (Crustacea). The female of this species has no limbs at all, and is attached to her host by a tube, which ramifies in its body like a system of roots and carries food to her, whilst a number of males, also without limbs, are attached to her near to her genital opening.

Among the Crustacea, also, is the group of parasitic *Rhizocephala,* which live upon crabs. All of them have lost their limbs, and all trace of that segmentation of the body which is characteristic of all arthropods, and of the complicated muscular and nervous apparatus associated with it, has gone. The alimentary canal has also disappeared. *Sacculina,* for example, already referred to, is little more than a simple flattened sac attached to the abdomen of the short-tailed crab, on which it lives, and in it there is little more than the genital organs.

Remarkable also is the parasitic shellfish *Enteroxenos ostergreni* found in the intestine of sea-cucumbers. To it remains scarcely any structure by which it can be recognised as a shellfish. To determine the relationships of such profoundly altered creatures we have to study the young that come from their eggs. The egg of *Enteroxenos* gives rise to a larva of the kind known as a *Veliger,* which brands its parent as a shellfish. The *Nauplius* larva of *Rhizorhina* and of other parasitic crustacea proves that they could not belong to any other group of animals.

CHAPTER VI

EFFECTS OF PARASITISM UPON THE PARASITE (Continued)

Though the parasite may lose its power of movement, it may acquire new features by way of compensation, and of these the tapeworm shows us one example. The body of this remarkable creature is a chain, often many feet in length, of flattened pieces budded off from a minute head shaped like a club. It has entered the alimentary canal of, say, a dog, which is full of a thick soup of half-digested food, in which the tapeworm must live; and this soup is being more or less constantly compressed and mixed and urged onward towards the vent by the rhythmical contractions of this alimentary tube. The tapeworm has no locomotor organs. How is it to hold its own in this tubular bath; how prevent itself from being swept on to the vent and out into the world where it would infallibly die?

It solves this problem in a way that to us human beings seems obvious. It anchors itself to the wall of the intestine by developing on its head four minute suckers. The oval ones of the beef tapeworm of man are about one-thirtieth of an inch long, and there are four of them at intervals round the head, which is not more than one-twelfth of an inch in diameter. They serve to hold in place a worm that may be a quarter of an inch in breadth and over thirty feet long. The other tapeworm frequently found in man, *Tænia solium,* the pork tapeworm, is usually smaller, but it has, in addition to its four suckers, a circlet of from twenty-five to fifty minute horny hooklets which help

the suckers to keep the worm in its place. Such suckers and hooklets are often possessed by parasites of all kinds.

Devices for attachment are, as we should expect, best developed in the ectoparasites, because these, being swept by the water or air in which their host lives, or exposed to its attempts to rid itself of them, need a firmer attachment. And Nature is entirely ruthless. She frowns on half-measures, and, having got rid of locomotor organs thoroughly, works towards the development of equally efficient anchors. Those individuals which fail to develop these are not successful and cannot propagate their kind, so that progressive efficiency in whatever type of sucker or hooklet has been evolved must follow. The same law holds whenever any other method of attachment is developed. The whipworm, *Trichuris* (Trichocephalus), for example, and all its near relatives, have not developed suckers or hooklets, but the front third or so of their bodies has become elongated and threadlike and is buried in the tissues of the host. The long protoplasmic process called an epimerite at the anterior end of many gregarine protozoa is another example of this method of attachment.

Just as locomotor organs may be lost by parasites because they are no longer useful, so the alimentary canal may be simplified or disappear altogether; and in this respect again we find degrees of simplification.

If a free-living animal accustomed to masticating solid food takes to parasitic life, the first change may take place in its mouth. Teeth that were necessary for killing and chewing up other animals are no longer needed for either purpose, although the food may still have to be digested, so that the rest of the alimentary canal is little affected. The modification of the mouth of the ectoparasitic insects is a good example of this. Typically an insect's mouth is provided with biting mandibles like those of the cockroach, suitable for

chewing small pieces of food that have been bitten off; but transient bloodsucking diptera, such as the mosquito, the horse fly, or the tsetse fly, all have, instead of such biting mandibles, piercing stylets with which the insect can bore through the skin of its host and reach its blood. The same is true of the lice, the fleas, and the bugs. Among *Arachnida* the ticks show a similar modification. Furthermore, the pharynx of such insects develops into a sucking pump, by means of which either blood or the juices of plants, which they also may suck, are brought up into the stomach.

The roundworms also show alterations in their mouths for a similar purpose. The mouth of *Ancylostoma duodenale,* the miner's hookworm, is shaped rather like a bell, and is provided with horny teeth with which it takes hold of the lining of the intestine. Through the wound thus made the worm sucks the blood of its host. The bloodsucking roundworms that can be such serious pests of sheep and other domesticated animals have a similar apparatus. Some of the eelworms, which cause such diseases of plants as "Earcockles" of wheat and "Tulip-root" of oats, have a spine which they work backwards and forwards, and with which they bore into the host plant. The leeches have numerous small teeth with which they make characteristic often tri-radiate wounds. Interesting also is the difference between the typical teeth of the bats, which are adapted for crushing either insects or fruit, and those of species which, like *Desmodus rufus,* suck the blood of man and animals. These repulsive creatures have developed razor-like incisors and canine teeth at the front of the mouth. With these they make horizontal cuts through which they suck blood; and the grinding teeth at the back of the mouth, being useless to an animal that feeds upon blood, are small and unimportant.

Most of the species just mentioned retain in varying degrees the rest of the alimentary canal. They

are parasites, but even when they live inside other animals they eat solid food, whether it be blood or tissues, and digest it. The common liver fluke of the sheep is similar to them in this respect. It lives in the bile ducts of the liver and feeds there on bile and also on blood which it obtains by breaking a way into the bloodvessels. Some blood-sucking species, such as the leeches, have developed a very capacious crop, provided with lateral pouches, in which they can store up enough blood to last them for more than a year. Such species usually suck blood only occasionally and this storage crop enables them to live between their periodical meals.

Very different from them is the tapeworm, which has no alimentary canal at all. We must suppose that its ancestors originally had one; but life for long periods in a bath of rich food in the intestine, food which it can absorb already half-digested through its soft skin, has rendered an alimentary canal unnecessary.

The ability of the tapeworm to absorb and utilise, without the help of an alimentary canal, the half-digested food of its host is very remarkable. It is one of the new characters acquired by these creatures as a result of parasitic life, and it directs attention to the fact that if structure is simplified by parasitic life, then physiological processes also must alter, for structure and function always go hand in hand. A change in the one means inevitable change in the other; and if in a free-living creature a number of organs are required to perform a certain number of functions, and one or more of these organs is removed or simplified, then the function it performed must either be taken on by the others or be performed in some other way. The end result in any event is that such vital functions as reproduction, digestion, respiration, excretion, and the transport of food and oxygen about the body and waste matter out of it, have still to be performed, but by fewer organs. The animal's physiological processes,

therefore, become more complex in the sense that they have to be effected with more economy of means.

How is respiration effected by the parasite, for example? The ectoparasite, living on the surface of either its terrestrial or aquatic host, is under no greater difficulty than its victim, and we do not find that its respiratory system undergoes any marked alteration as a rule. But the endoparasite, living in the alimentary canal or in the tissues, must somehow find and take in oxygen. In the tissues themselves, bathed as they constantly are by the lymph, a fluid whose function it partly is to carry the oxygen to all parts of the body, the parasite is lodged amid plenty. In the blood, likewise, the malaria parasite and the trypanosome have entered a medium which not only carries food in solution to the body, but oxygen as well. Even sarcoptes, the mite that causes scabies of man, burrowing deep in the skin, can get its oxygen through the small tube that it digs. But in the intestine, bathed by digestive ferments, acid, alkali, and the gases that the digestive process produces, how does the tapeworm or the entamœba fare? This is a problem that still awaits clear explanation.

Such endoparasites as live in the stomach itself, such as the larva of the horse bot-fly *Gasterophilus* or the worm *Hæmonchus contortus* that lives in the fourth stomach of the sheep, presumably can get enough of the vital oxygen from the air swallowed by their hosts with their food. The larvæ of the sheep nasal fly *Œstrus ovis,* which are laid by the adult two-winged female fly in the nostril of the sheep, and subsequently crawl up into the spaces in the skull behind the nose and set up serious inflammation there; or those, such as the larvæ of *Lucilia cæsar,* the green-bottle fly, which may attack in a similar way the nose and ears of man in the tropics, often causing frightful sores and ulcers; or others, that may burrow under his skin (species of Dermatobia, Hypoderma, Cordylobia,

etc.) or be deposited in foul wounds and live there much as blowfly maggots will live in decaying meat—all these are in sufficient contact with the oxygen of the air for their needs. But the means by which the gut parasite satisfies that oxygen hunger which is common to all living things has not yet been satisfactorily explained.

Experiments done by Weinland on the parasitic worms suggest a possible explanation. He found that these worms contain a much higher percentage of the starchy substance glycogen than do animals as a rule, and it has been suggested that such creatures may obtain their oxygen by the breakdown of this substance. If this is true, it is an interesting instance of the acquisition of a special physiological habit by a parasite as a direct result, we may suppose, of its parasitic life. Some of the special modes of feeding shown by certain of the bacteria may be examples of a similar adaptation along different lines.

We ought to remember, however, that some of the bacteria have developed a power of living without any oxygen at all. They are what are called *anaerobes*, some of them being incapable of living in a medium containing oxygen (obligatory anaerobes), and some able to live either with or without it (facultative anaerobes). Some of the parasites living in the intestines of animals may have acquired a similar faculty.

The blood and the system of tubes by which it is carried throughout the body of those animals which possess it must always be considered in relation to the respiratory system; for one of the functions of the blood is to carry to every part of the body the oxygen taken in by either the gills or the lungs, or by both. Any change in the method of taking in oxygen must therefore be followed by changes in the blood vascular system; and if creatures which possess a well-developed blood vascular system become parasitic to such a degree that their respiratory organs are pro-

foundly modified, the blood vascular system will be modified also. As a matter of fact, very few profoundly modified parasites are descended from ancestors with a well-developed vascular system. The insects, which do possess such a system, have not, as adults, at any rate, gone further than ectoparasitism, and we note in them, therefore, little more than a simplification of their blood vascular system if there is any change in it at all. The flatworms, which are most modified, come from ancestors which had not yet developed a vascular system.

It is, perhaps, significant that so few creatures with an efficient blood and channels for its transport have taken to the parasitic life. It may mean that the evolution of this blood and its system of transporting vessels conferred on its owner such a great physiological and evolutionary advantage that, like the vertebrate with its greatly superior organisation and control, it never experienced the need to explore such bypaths of life as the parasitic habit.

Excretion of waste, that other vital necessity of living things, presents no greater difficulty as a rule to the parasite than to its free-living relative.

But one other structural unit of the body remains to be considered, the most important one of all in some respects—the nervous system. What effects does the parasitic life exert upon that? We are still, of course, on the threshold only of our understanding of the nervous mechanism of animals; and the difficulties in the way of studying its operation in the parasite are very obvious. For to do this we must observe the animal in its natural surroundings, and we know as yet no way of reconstructing in the laboratory the interior, say, of a sheep's liver full of flukes, or the intestine of a man with tapeworms in it. But we can see certain obvious facts.

We note, as before, the loss of organs that become useless. Just as the eyes of the cave newt are covered

with skin, or those of the burrowing mole are reduced, so the eyes of a creature that takes to parasitic life tend to disappear. We can trace if we like a whole series of similar losses, a reduction and eventual disappearance of some organs that were essential to the free-living creature which needed to be very keenly aware by smell, hearing, and sight of all that went on around it. The same principle operates as brought about the loss of locomotor organs; and just as in that instance whenever the young stages of the parasite were still free living—as, for example, the young miracidium and cercaria larvæ of the liver fluke—the locomotor organs were retained, only to be lost when either that stage or the adult became parasitic, so the young phase of a parasite may have sense organs and lose them later. The same miracidium larva, for example, has two eyespots at the front end of its conical body; but the adult fluke has no eyes. Associated, perhaps, with changes of this kind in those parts of the nervous system concerned with the perception of light must be reckoned the loss of colour by such forms as the tapeworm, which, like the white cave newt, lives in darkness; and also certain resemblances in colour and pattern between ectoparasites and their hosts, which must be regarded as protective adaptation.

The nervous system itself is liable to disuse in parasitic life. Its primary function—to inform its owner of what goes on in the environment and to correlate the bodily activities, both internal and external, to those happenings—loses much of its value when any creature gives up active life or enters the body of another. But we ought to remember once more the points we made about the blood vascular system. The nervous system is less altered in the ectoparasite than in the endoparasite, and probably few parasites have had ancestors which possessed a really highly developed nervous system. Again, we note that the insect parasites were originally best equipped in this respect. The flatworms

never had more than a rudimentary nervous mechanism, the protozoa none at all. And perhaps it is also true that those creatures which did develop an efficient nervous system thereby acquired, as the vertebrates did, for example, so great a potential mastery of their environment that a free life of initiative and adaptation in the world outside never presented any serious difficulty to them. They could always find a corner in which to live and maintain their kind, so that even the bitter struggle for life could not force them to explore the ways of the parasite. It is not that they would have found an easier life if they had done this, for the parasitic life is by no means free from struggle; but no need arose to turn from the outer world.

We must not forget, however, that the parasite is exposed, no less than its free-living relative, to stimuli of all kinds that come from its surroundings. To exchange life in a pond for life in a gut does not mean freedom from prickings: and these it is the function of the nervous system to record. Thus to *tactile* stimuli parasites must be sensitive, to temperature changes they may be very sensitive, and above all things that influence the lives of parasites, especially those of endoparasites, the influence of chemical substances must be particularly important. Responses to these are called by the general term *Chemotaxis*. Upon them depend, perhaps, the often astounding and very complicated journeys made through the body by such creatures as the roundworm *Ascaris*, which will regularly leave the intestine where it is born and bore its way into the blood stream, by which it is carried to the liver. From there it is carried through the right side of the heart into the lung, and it then either crawls up the air tubes into the back of the mouth or irritates the lung so that it is coughed up. From the back of the mouth it then finds its way down the gullet into the stomach and so back to the intestine, where it grows up.

Other journeys are still more remarkable. The young of the miner's hookworm bores through the human skin. By what means does it find its way through the maze of tissues and influences within the body to the small intestine which it must either reach or die? The minute sporozoite, not more than one four-thousandth of an inch in length, that is the earliest stage of the gregarine protozoan parasite *Monocystis,* which lives in the vesicula seminalis of the common earthworm, must enter its future habitat with the earthworm's food. Set free in the gut, it immediately bores into the tissues; and somehow it finds its way to those pouches in the ninth to the twelfth segments of the worm where its future life is to be lived. The eggs of the warble fly *Hypoderma* are laid on the hairs of a cow. Grubs emerging from them crawl down the hairs to the skin, bore their way through it with their strong mouth hooks, and for seven months wander about in the body of the cow, moulting during this period and growing to five times their original size. Then they find their way to a position underneath the skin of the back of the cow, cut a hole in this through which they may breathe, and, moulting several times, grow rapidly, feeding on the matter of the sore which they produce. Finally, they work their way out of the sore when they are full grown, fall to the ground, and seek shelter under anything available, and then become chrysalises, from which the fly emerges to start the same cycle again.

The mechanisms by which such amazing migrations as these are controlled are as yet unknown. But it is more than likely that a large part is played in them by what are called *Tropisms* of various kinds—that is to say, by regular responses by the creatures concerned to various stimuli from their surroundings.

Nor should we forget, when we are considering parasites, what Brumpt has called Histotropism—the attraction exerted by certain tissues of the animal body

for certain parasites. The entry of the young forms of the hookworm into the skin of man, or that of the larva of the warble fly into the ox's skin, may be so caused, as may be also those instances of the migration of a parasite to a particular tissue such as the "preferences" for certain parts of the body mentioned in Chapter IV. But to call such phenomena instances of histotropism does not, it must be confessed, explain very much. We are as far as ever from really understanding how they are caused. It may be that these journeys are nothing more than the normal escape of the creatures concerned from environments that are unsuitable to them; but such a simple explanation will not account for the regularity with which they are carried out, nor for the remarkable accuracy with which the parasite reaches its proper destination. The truth is that we know very little about these matters at all.

CHAPTER VII

ADAPTATIONS OF THE PARASITE TO ENSURE ITS SURVIVAL

The reproduction of its kind, dispersal of them over the earth, and the adoption of various means to ensure the survival of its species, are, perhaps, the most fundamental instincts of every animal; and the operation of them in the parasite must now be considered. To the power of their influence must be ascribed that remarkable feature of all parasites, the size and complexity of their reproductive organs. Their other organs may be simplified or lost as a result of parasitism—almost every other structure of the body may, as we have seen, be discarded—but the genital glands remain; and whatever the degree of modification in them, it is more marked, as it is in other structural features, in the endoparasite than in the ectoparasite.

One reason for this increase in size and complexity of the reproductive organs can be seen when we inquire why it is that the parasite can produce as a rule many more eggs and sperms than its free-living relative can. The number of eggs produced, especially in instances of advanced parasitism, is astounding. It has been calculated, for example, that *Tænia solium,* the pork tapeworm of man, can lay forty-two million eggs; that *Ascaris lumbricoides,* the common roundworm of the pig, can lay as many as sixty-four millions; and that *Tænia saginata,* the beef tapeworm of man, can produce one hundred and fifty millions. Such remarkable fertility may be compared with that of the lower vertebrates such as the fishes, and may be equalled also by animals that lead a sedentary life; and in all these instances the reason for it is the same.

Both eggs and young, defenceless embryos are con-

stantly being destroyed by other animals which regard them as attractive titbits, and by such adverse influences as drought, heat, and frost. For the parasite there is the further problem that its young must find its right host, or more than one such host. The dice are thus heavily loaded against all eggs and embryos that are not under parental care, and to meet these odds large numbers of young are produced so that the greatest possible number may survive. Conversely it is true that, when parental care confers upon the offspring, and through it upon the species, a great advantage, as happens among the four-footed, hairy, hot-blooded mammals which suckle their young, then the number of eggs produced by the female in her lifetime is relatively smaller, and the number actually fertilised perhaps smaller still. We can state it as a general rule, therefore, that in the animal world the number of eggs produced is directly related to the chances of their subsequent survival, although to this, as to every other biological law, there are exceptions.

Not all parasites, for example, rely upon mere mass production of eggs as a means of improving their chances of survival. Eggs have to be fertilised as well as laid; and this may be difficult for the parasite to accomplish, especially if, as so often happens, the locomotor organs have been lost or reduced. The sedentary animal has the same difficulty, and neither it nor the parasite can rely, as can the equally immobile plant, upon the chance that other animals will transfer its sperm to the egg. Some parasites have, therefore, like some sedentary animals, adopted means of making fertilisation easier.

The two sexes may, for example, become more or less permanently associated. The fluke *Schistosoma* (*Bilharzia*) is an example of this. Though the sexes of this worm are separate—it is one of the exceptions to the rule of hermaphroditism referred to below—the male worm folds over the edges of its flattened body

to form a groove in which the longer and cylindrical female usually lives. A more advanced instance is the roundworm *Syngamus trachealis,* which lives in the windpipe of chickens and other birds, causing the disease called gapes with its constant yawning and outstretching of the neck. This is another unisexual species, and the smaller male is permanently attached to the female at her genital opening, the two together forming a Y-shaped individual. Of a different kind is the association of males and females shown by the whipworm *Trichosomum crassicaudum*, parasitic in the urinary bladder of the rat, the female of which keeps two or three males actually inside her uterus. The small males of the parasitic crustacea, referred to in Chapter V., and those of the curious fishes *Photocorynus spiniceps* and *Edriolychnus schmidti,* are examples of another means still of ensuring the fertilisation of the eggs, for the males of these species have become parasitic on the females, a condition of things that is not unknown in human society, and their structure has suffered accordingly.

Another and more efficient method of attaining the same end is the complete abolition of the distinction between the male and the female and the production in one and the same individual of both eggs and sperms. This is called *hermaphroditism,* and it is worth noticing that, just as the sedentary animal often shows the simplification and loss of structural features so common in the parasite, so it is also often hermaphrodite. This fact, that the parasite and the sedentary animal continually remind us of each other, is important. It means, not that the one is necessarily related to the other, but that the parasitic life approaches the sedentary state and produces like results. Any resemblances between parasitic and sedentary creatures are therefore due, not to genetic affinity, but to the influence upon different stocks of similar ways of life, a principle which the biological philosopher calls Convergence.

The extent to which hermaphroditism has been adopted by parasites is remarkable. It is one of the reasons why their reproductive organs are so bulky and complex, and the causes of it are not confined to the need for easy fertilisation. For hermaphroditism does not necessarily mean self-fertilisation. It is possible that this is effected by some of the liver flukes, but cross-fertilisation is the rule, and perhaps this is imposed by the laws of evolution as a necessity if a vigorous stock is to be maintained.

The tapeworms, each segment of which contains both male and female genital glands, present a special difficulty in this respect, for it is not easy to decide whether each of these segments is to be regarded as a separate individual, or whether the whole worm is the individual and each segment a part of it; but the fertilisation of the ripe eggs in any one segment by the sperms also produced by that segment is prevented by the fact that the sperms are developed first and the eggs ripen later, so that any one segment rarely contains both at the same time. The eggs in each must therefore be fertilised by the sperms of another segment, and the movements executed by the worms in the intestine are doubtless due in part to the efforts of the segments to approximate themselves to one another for the transference of sperms.

If the normal processes of sexual reproduction may thus be modified by parasites to their own benefit these are not the only means at their command of improving their chances of survival. They can also multiply their numbers at some stage or other of their life history by some form of asexual reproduction. From the egg of the common liver fluke of the sheep, for example, emerges a microscopic ciliated larva, which after a free life in a pond or a ditch, bores its way into the snail *Limnæa truncatula;* and inside the tissues of this snail it becomes a little sac called a sporocyst, from the walls of which a generation of small tubular

organisms, each with a blind intestine, develop. These are called rediæ, and they also bud off from their interior other rediæ. A fourth generation arises from these in a similar way, but this is different. It is called a cercaria, and it has a minute oval body with a forked blind intestine like that of the adult fluke, and a tail by means of which it can swim in ponds and ditches after it has left the snail. Its business is to find its way to the alimentary canal of the sheep; and it does this by swimming to the margin of the pond or ditch, wriggling up the banks and on to the grass of wet pastures. There it forms round itself a hard case which protects it from heat and drying, and in this it awaits the moment when the sheep crops the herbage. Once inside the sheep's stomach, it leaves its case, finds its way to the bile ducts of the liver, loses its tail, and grows up into the adult fluke.

Such a life cycle gives some idea of the odds against the survival of a parasite. If the miracidium does not meet with a snail it quickly dies. Moreover, it can live in one particular species of snail only and must find a member of that species. Even if it finds the right one and multiplies in it, the cercaria that emerges again may die before it reaches the pasture; or if it reaches the grass it may not be eaten by a sheep before it dies; or some other herbivorous animal whose digestive juices it cannot resist may swallow it. To meet these odds the parent fluke produces great numbers of eggs in the first place; and each of the embryos emerging from this is again multiplied by the generations produced asexually in the snail. Such multiplication by a larva by asexual methods is called *pædogenesis.*

We see it also in the cystic stages of such tapeworms as *Tænia cœnurus,* which causes the disease called staggers or gid in sheep, and *Tænia echinococcus,* which may cause hydatid disease in man. In these instances the parent worm produces its eggs in the ali-

mentary canal of a vertebrate host. *Tænia cœnurus* lives in the gut of the sheep dog and other dogs. Its eggs, passed out with dog's excreta, lie on the pastures and are eaten with the grass by the sheep. In the sheep's intestine a small embryo emerges from them which bores its way through the wall of the gut and gets into the blood system. By the blood stream it is carried all over the body, and, reaching the smallest bloodvessels or capillaries, passes through their delicate walls and makes its way into the surrounding tissues. Here it settles down; and in this particular species it develops best in the nervous system. If it lodges in the brain, for example, it grows into a small bladder full of fluid sometimes called the *Cœnurus,* and as this increases in size there appear on its inner walls small buds which are really the heads of tapeworms turned outside in, each of them complete with the typical four suckers. Hundreds of these may be formed, and they cannot develop further unless they are swallowed by a dog, in whose intestine they grow up into tapeworms again.

From the parasite's point of view, therefore, the best result of the disease caused by the pressure of the cyst is that the sheep should die, or be killed by the farmer and its head thrown away; and this actually happens on farms where the farmers are careless or ignorant of the parasite's life history. It would also happen in a state of nature, where the sheep would either die or be killed and its carcase, including the head, would be investigated and eaten by dogs or, in the wild nature of earlier times, by wolves, and with it the cyst would be swallowed. In this way a dog may infect itself, even by devouring a single cyst, with hundreds of tapeworms.

Tænia echinococcus is another tapeworm which multiplies its numbers inside a cyst full of fluid. It also lives in the dog's intestine, and its eggs may be swallowed by human beings who eat raw vegetables or salads which have been fouled by the solid excreta of infected dogs. If this occurs the embryos emerging

from these eggs may find their way to the liver of man and there give origin to a cyst even bigger than that produced by the young of *Tænia cœnurus*. On the inner walls of this bladder, not only the heads of potential tapeworms may develop, but also daughter cysts. These daughter cysts may even give rise to granddaughter cysts, and in both of these many tapeworm heads may appear, so that in the whole cyst there may be enormous numbers of potential tapeworms. Such a cyst is called by the doctors a *hydatid cyst*, and it may reach the size of a baby's head and cause, like the similar cysts mentioned in Chapter IV., very serious trouble by pressing on the liver, the lung, the intestines, or important nerves or bloodvessels in its neighbourhood. But otherwise it is usually harmless. The tapeworm heads inside it cannot develop further in the human body. They can only develop if the cyst is eaten by a dog, so that it is certainly a calamity for the tapeworm if its eggs are nowadays eaten by a man. If any other mammal swallows them, there is, of course, more chance that a dog may eat its carcase and so enable the thousands of heads in the cyst to grow up into tapeworms again.

Both these instances are examples of larval multiplication called pædogenesis, and the total effect of both this and the enormous numbers of eggs produced is to counteract the difficulties to which the parasite's complicated life history exposes it and to increase its chances of survival.

Most other tapeworms rely upon the large number of eggs alone. Each egg, for example, of the pork tapeworm of man gives rise, if it is taken in by a pig, to an embryo which grows into a cyst in the muscles of the pig, but this cyst contains only one small tapeworm head. If a man eats raw or insufficiently cooked pork containing such cysts, from each a single tapeworm will emerge, but only one. This may seem to lessen the chances of the pork tapeworm's sur-

vival, but we must remember that carnivorous animals do not cook their food, nor did man before civilisation and such influences as the Mohammedan or Jewish religions began to interfere with Nature's ways.

We may sum up the matter by saying that to meet the chances against its embryo ever getting into the second host in which it must live part of its life, the tapeworm produces enormous numbers of eggs; and to meet the chances against its ever getting out of that second host again and back into the right first host, the cœnurus and the hydatid cyst have been developed.

Among the parasitic members of the *Hymenoptera,* the group of insects to which the ants and bees and wasps and sawflies belong, there is another method by which the offspring may be multiplied, a method which is called *polyembryony,* or the production of more than one embryo from each egg. The egg of *Ageniaspis* (Encyrtus) *fuscicollis,* for example, which is parasitic on the injurious small ermine moths of the genus *Hyponomeuta,* undergoes a kind of budding to produce a row of embryos enclosed in a tube, all of which may ultimately grow into adults. This also can be considered as a means of increasing the chances of the survival of the parasite.

Under this heading also we should, perhaps, include *parthenogenesis,* the development of offspring from the unfertilised egg. For it is quite evident that if the egg need not be fertilised, one important category of menaces to survival—namely, all those influences which prevent the union of the adult sexes—may be avoided. A few parasites, such as the tick, *Amblyomma agamum,* and some of the parasitic *Hymenoptera,* show no other method of reproduction. In other instances, such as the various species of greenfly that show it, parthenogenesis occurs only in the spring and summer, and the onset of winter determines the production of a male and female generation.

CHAPTER VIII

ADAPTATIONS OF THE PARASITE TO ENSURE ITS SURVIVAL (*Continued*)

AMONG the adaptations which help the species in the battle for survival we must also reckon those powers, possessed by the young stages of many parasites, of resistance to such inimical climatic factors as heat, frost, and drought. The embryo is often the most vulnerable phase of an animal's life, even when that animal is accustomed to the battle of life in the outside world. The ectoparasite is, of course, still exposed to a large extent to the rigours of this physical world, so that we find that its young stages are not very different from those of other free-living animals. But the endoparasite, accustomed to life inside another animal, must make some provision for its young if they have to leave the shelter of the host, and, for a while at least, live outside it. This provision usually takes the form of some kind of protective envelope, like that, for example, which encloses eggs, or the hard wall or *cyst* in which are protected the germs of the amœba which causes dysentery. Such cysts are always produced by those parasites which, without any effort on their part, reach their host by what can be called the *contaminative method*—that is to say, by the contamination of the host's food and drink by these resistant phases.

From the eggs of most parasitic roundworms, for example, such as the one which lives in the fourth stomach of the sheep, an embryo emerges which, after one or more moults, may remain enclosed in the dried and thickened last skin that it sheds, and thus may resist for long periods the rigours of climate that pass across the pasture on which it lies. The powers of re-

sistance of some cysts of this sort, and also of eggs, are very remarkable, and they are important aids to survival. It is often essential, moreover, that such resistant phases should lie thus outside the host for a certain period, because usually the embryo of a parasite cannot infect a new host until it has undergone definite biological changes which result in its becoming "infective"—that is to say, able to infect a new host.

The necessity for such power of resistance to rigours of the external world is greatly lessened when a parasite adopts a second host as well as a first one. An example of this was given above when the life history of the liver fluke was described. Two facts will be noticed about it. First, that the egg of the fluke has to suffer far less life in the outer world, because part of its life history is passed inside a snail; and, second, that it cannot infect another sheep until it has passed through a biological cycle in a particular species of snail—namely, *Limnæa truncatula* in this instance.

The young of the broad tapeworm of man, *Dibothriocephalus* (Diphyllobothrium) *latus,* must even pass through the so-called water-flea, cyclops, and a fish which swallows this, so that three hosts are required.

When parasites thus live inside the bodies of two or more hosts instead of one, and are alternately passed from one to the other, we speak of an *alternation of hosts.* The host in which the adult stage of the parasite lives and in which sexual reproduction takes place if it occurs inside the host at all, is called the *definitive or primary host;* that in which other phases of the parasite live and in which asexual reproduction may occur is called the *intermediate or secondary host.* Thus the primary host of the common liver fluke, *Fasciola hepatica,* is the sheep or some other mammal; and its intermediate host is the snail *Limnæa truncatula.* For other species of fluke the species of snail that can alone act as their intermediate hosts is different. Many other parasites are in a

similar way restricted to only one species of intermediate host, so that one of the problems of their life-histories is that they have to find this particular species of animal and enter its body; for no other species will do, not even nearly related species of the same genus. Less commonly parasites are restricted also to a single species of primary host. The tapeworms, *Tænia solium* and *Tænia saginata,* for example, can live in man only; and repeated attempts to rear them in the dog, which is such a favourite host of the tapeworms, have failed completely. *Tænia crassicollis* adheres to the cat very closely, and *Trypanosoma lewisi* to the rat. Most trypanosomes, on the other hand, can live in the blood of more than one species of vertebrate, and the same is true of many parasites with both primary and secondary hosts.

Parasites which are restricted to one species of either primary or secondary host, or of both, are obviously at a disadvantage, for their close adaptation to these hosts not only makes it easier for us to control them, but also increases the difficulty the parasite always has of finding its right host. This difficulty is increased when the parasite does not pass, as the liver fluke does, part of its life inside its two hosts and part in the outside world, but lives the whole of its life inside one or other of its hosts and never enters the outside world at all. Such a parasite does not need to make protective cases for any stage of its life history; but, although it benefits by the continuous shelter provided by its hosts, this benefit is neutralised by the fact that it is now entirely dependent upon these hosts. Further, it is usually conveyed from one to the other of them passively and has paid for its shelter by loss of the power of entering either host by an active effort of its own.

Consider the protozoan parasite, *Plasmodium,* which causes malaria in man. It lives in his blood, and this blood is sucked up by a mosquito, in whose stomach the males and females only of the *Plasmodium* survive

the action of the mosquito's digestive juices. They produce in the stomach male and female elements which unite to form a fertilised egg, or zygote, and this becomes itself parasitic on the wall of the mosquito's stomach, growing there in the form of a soft-walled cyst, inside which countless small germs called sporozoites are produced. This cyst then bursts into the mosquito's blood, and by the blood the sporozoites are carried to the spittle glands, and from them are injected back into the human blood when next the mosquito bites a man.

The trypanosome that causes sleeping sickness in man has a cycle that is similar in principle. It lives in the blood and cerebro-spinal fluid of man and is taken up by the bite of a tsetse fly, in whose intestine it undergoes a definite biological cycle, and until this has been completed it cannot again live in human blood. That infections of man do occur without the completion of this cycle is quite true. Tsetse flies, immediately after they have taken up trypanosomes, may again bite a man while their mouthparts are still wet with the blood of their first bite in which blood trypanosomes are swarming. Such *direct* transmission has been responsible, in part at any rate, for epidemics of sleeping sickness in Africa; but it is nevertheless exceptional and the rule of *indirect* transmission after a definite cycle has occurred in the fly, still holds.

Yet another example of this kind of life history is that of the flagellate protozoa of the genus *Leptomonas* which have not adopted an animal, but plants of the group *Euphorbiaceæ,* as their hosts, in the latex of which they live and into which they are injected by the bites of hemipterous insects or bugs which suck the juices of these plants.

Examples could be multiplied: but enough have been given to emphasise the increase of difficulties before the parasite which, like the ones just cited, must not only go through a biological cycle in the

second host as well as in the first one, but must also rely for transmission on the *inoculative method* by the bite of some other temporary ectoparasite which conveys them as passengers which make no effort on their own behalf.

That such difficulties are real is proved by the fact that some of these parasites have evolved what must be regarded as a means of counteracting them. If they do not multiply in their larval stage as the liver flukes do, they can multiply their numbers by a series of generations produced by the asexual method of division into a great many parts. This division occurs, for example, fairly regularly at intervals of three days in one species of the malarial parasite of man, and to it is due indirectly the regular attack of fever characteristic of that disease.

Such asexually produced generations, however, are usually the ones that cause the damage that the parasite does, and they may increase the numbers of the parasite to such an extent that the organ in which it lives is completely overrun by them, as the intestine may be overrun, for example, by the protozoan parasite that causes a form of white diarrhœa in poultry and cattle and other animals. The damage done thus may be so great that a violent diarrhœa results, by which many of the parasites are swept to certain death in the world outside, or the host is killed, and with it all the parasites in it, so that all the advantage gained by increase in numbers is neutralised, at any rate so long as the host remains susceptible or ill-adapted to the parasite's effects upon it.

We can further realise the actuality of this risk for the parasite of non-transmission to its primary host if we consider what has happened to the malarial parasites of man which were injected by mosquitoes during the war into many English soldiers in the East. While the soldiers remained abroad the parasites found no difficulty in completing their life cycle. Mosquitoes

bit Tommy Atkins freely and took up parasites from his blood, harboured them in their bodies until they produced countless sporozoites, and injected these again into the soldiers. Thus malaria spread and was able, notably in East Africa, to put whole battalions out of action. But in course of time these battalions were sent home to England; and in most parts of England there were no mosquitoes to bite the men and enable the parasites to develop. In some parts of England, it is true, there were; and there was for a time a real danger that these mosquitoes, which were until then clean of the malarial parasite, might take it from these men and so become capable of passing the disease on to other English people. But that danger is practically over. Most of the mosquitoes of England were not of the right kind, for fortunately the malarial parasite cannot develop in every kind of mosquito. It has become adapted only to life in certain species of mosquito, and where that species does not exist the parasite cannot live nor the disease occur. Not only this, it is confined only to the females of this species, for the female mosquito alone is a blood-sucker, the male feeding on the juices of plants.

The same close adaptation to a particular kind of intermediate host is characteristic, though less strictly, of the trypanosomes that cause sleeping sickness. These parasites, in the course of a long life of parasitism, have acquired the power of living harmlessly in the blood of the antelope and other big game and domesticated animals of Africa; and from this they are usually taken up by the tsetse flies, pass through a definite cycle in the intestine of these flies, and are injected back again. Where the tsetse fly does not or cannot live, therefore, these particular trypanosomes cannot live either, so that the distribution of the one corresponds exactly to that of the other. If we could remove the fly we could destroy the trypanosomes: and the same result would be obtained by the destruction of the

mammals which harbour these tyrpanosomes in their blood. The latter expedient has actually been proposed, though it is scarcely practicable; and, as Professor Duke has recently pointed out, to remove these animals from the vicinity of man simply means that we remove the normal food supply of the tsetse fly and so provoke it to bite human beings and infect them. An increase and not a decrease of sleeping sickness would therefore follow.

Such parasites as these just mentioned must be regarded as much more advanced in parasitism than, say, the liver fluke or the tapeworm, because they have lost the power of living outside a host of some kind. They are, therefore, entirely dependent on their hosts, and frequently need particular species of such hosts or even, as in the instance of the malarial parasite, the females of it only. The malaria parasite, indeed, boxed up as it is in the blood of, say, an Indian soldier, is like a prisoner in a well-guarded dungeon. It can live there, it is true, for very long periods, perhaps throughout the life of the soldier, but only a certain female can let it out, only the female of a certain kind of mosquito; and it must rely on her hunger-instinct for deliverance.

The adoption of a second host cannot, therefore, be regarded as always advantageous to the parasite. It is doubtful whether it reduces or increases its chances of survival. But we must remember always when we reflect about such matters as this that the parasite has no choice; it is driven by the law of the survival of the fittest and by whatever other evolutionary factors biologists may yet discover.

We cannot say yet how the malarial parasite first acquired the habit of passing part of its cycle in the mosquito. Authorities have so far failed to decide with unanimity whether it began first in the mosquito or in the blood of man. It is certainly hard to understand how a small and very delicate amœba like

the malarial parasite could have begun its parasitic life in human blood. How could it have got there in the first place? But if it was originally a parasite of the insect, it is easy to understand that some parasites could have been injected into human blood when the insect sucked that blood, and in that way entered man. Originally most of the parasites thus injected must have died, being killed by the marvellous power of the blood to battle with and destroy any foreign invader. But even if the early invaders were killed, some of those subsequently injected might survive; and they would cause a reaction of the man infected which would take the form of fever and the other manifestations which we call malarial fever or ague. That parasites still cause this reaction—this attempt of the human organism to rid itself of the parasite—means that the parasite has not yet adapted itself completely to life in man. For it is obvious that it is to its advantage not to cause such a reaction, but to live in harmony with him as it does with the mosquito in which we may suppose, because it causes no apparent disease of that insect, it has been parasitic for a long enough period to enable it to become completely adapted.

The still more striking instance of the *Trypanosome* supports this theory further. Whether these minute and beautiful ribbons of protoplasm moved by a long and exceedingly delicate whip were originally parasites of the digestive tract of the tsetse fly or of the vertebrate blood cannot yet be decided. But certainly some of them seem to have begun in their invertebrate hosts. If we take the one that causes the disease called nagana in cattle as an example—namely, *Trypanosoma brucei*—we know that it passes part of its cycle in the gut of the tsetse fly, *Glossina morsitans,* living there in perfect harmony with the insect and causing no disease. It can also live in other species of biting fly. So that its chances of transmission from vertebrate to vertebrate are greater than those of the malaria parasite.

Moreover, it is less rigidly adapted to particular species of vertebrate host, for it normally lives in the blood of several kinds of wild ungulates in Africa and causes in them no disease. But if a tsetse injects it into the blood of domesticated cattle it causes in them the disease called nagana. It is, in other words, not yet fully adapted to life in the domesticated cattle; and injection into them is, without doubt, a calamity for it, for it must result in the sickness or death of the cattle, which means that many or all of the parasites in them are destroyed. If this parasite is injected by the tsetse fly into man, as has happened in Rhodesia, the result is still more calamitous for the parasite. It produces in man a very severe and often fatal form of sleeping sickness, which must result in the death of great numbers of the parasite.

The fact that this particular species of trypanosome has comparatively recently acquired the power of living in the blood of man is obviously an instance of a parasite in the early stages of adapting itself to new vertebrate hosts. In course of time, we may be sure, man will suffer less from this kind of sleeping sickness, partly because he will adapt himself to it and partly because the parasite will adapt itself to him. There will thus very slowly arise a state of affairs like the greater tolerance, as we say, of the African native to the ordinary form of sleeping sickness caused by *Trypanosoma gambiense*. The native suffers from it less than the white man because he has had longer time in which to try to adapt himself to it, and the parasite has also had longer time to grow accustomed to life in the native's blood. The malarial parasite has approached even nearer to that state of mutual tolerance between host and parasite which is the parasite's ideal, for we might almost say that nearly every native in some parts of the tropics has had malaria in youth and tolerates it throughout life without such serious effects as the white man, less used to it, must suffer. *Entamœba*

histolytica, which causes a human dysentery, shows an even closer adaptation to its host, for it has been calculated by Dobell that seven to ten per cent. of even the population of England harbour this parasite. It is constantly doing minor damage to them, but that damage comparatively rarely amounts to the proportions of a disease. The percentage in tropical countries is much higher. It is easy also for anyone with a microscope to discover that in such countries as China and Arabia, where food is frequently contaminated as a matter of course or policy by human and animal manure, almost every individual harbours worms of various kinds in his intestines. Yet such is the natural balance between worm and host that most of these individuals are healthy enough.

Such facts as these teach us that the opinion so often expressed that a parasite is always dangerous is not correct. If we look at it as the human being naturally does, as an unclean invader of our bodies, and of the bodies of other animals, we must take such a view. But if we see it as we ought to try to see it, from its own point of view, we shall get a truer conception and shall realise that it is to the very great disadvantage of a parasite to cause disease in its host. For disease means reaction against it. The two terms are synonymous; and even the human being parasitic on his own community is wise enough to see that to provoke such a reaction is very foolish.

The fact remains, however, that the parasite does cause disease. It does so when it first explores new hosts, and it may not survive such attempts to conquer new pastures. It also causes disease by lowering the resistance of its host to other parasites. A man full of tapeworms, a lamb with a hundred and twenty feet of the tapeworm *Moniezia* stealing the food from its intestine, are not in good health, although these particular parasites may not be hurting them to the point of sickness. But their strength is lessened, and other

parasites, especially the bacteria, may overcome them then. Whether the parasite or the host wins will depend upon the reserve strength of either; and that in a nutshell is the secret of all recovery from disease.

We have learnt, then, that equilibrium between the parasite and the host is the best for both: that the parasite does not always cause disease, though it always does damage; that it does most harm when it first attempts to adapt itself to a host it has never entered before; and that, whatever the equilibrium that is eventually established between the two, this is always liable to be upset by any sort of influence, whether it be another parasite, a mineral or animal poison, or a sudden change of temperature or other effect of the environment, which lowers the general health of the host. Such disturbance of the equilibrium usually damages the parasite, for if it takes the form of an increase of the host's resistance, the parasite must find it more difficult to live, and if it is affected by the host's loss of health the parasite is generally destroyed in great numbers. And in taking this view we have tried to avoid the common error of attributing a knowledge of purpose to the parasite. It has not adopted the parasitic mode of life from choice. Unlike the human "sponge," it could not say to itself: "Here is a way, with the sacrifice of some independence and honour, of having an easy time in a bitter world." If it could have thought so, it would have been quickly disillusioned, as the preceding pages must have shown. Nor does the parasite know that it is to its detriment to kill or cause disease in its host. It is more like the wild cat that will kill all its food supply from sheer lust of blood and then starve; and it may be that some of the elaborate reproductive adaptations shown by parasites, and, indeed, by all living things, are Nature's way of guarding against this repercussion of her law that the animal, for reasons given in the first chapter, must kill and eat. To breed and propagate the species is another

primary need of living things, and usually this predominates. But the former may go near to the extermination of all food and so prevent the possibility of the latter. This is so, we must believe, only when the balance that Nature insists on in the long run has been upset. Ultimately, given the time she so generously allows herself, she works back to an equilibrium that gives a fair chance to all.

Arguing thus, we may feel a sudden qualm, for is not such a theory merely another example of that almost inescapable bane of ours, the human point of view? We will, as men, to be just; and we speak of laws and fair chances and enough for all. But what do we mean when we speak of Nature's laws in this sense? Do we mean just ourselves?—that we are judging parasites by human standards and cannot understand why a trypanosome, for example, should be such a fool as to multiply to such an extent that it kills both its host and its progeny? The truth is that, given conditions that are sufficiently favourable, it will do so; instinct, the blind urge of sex, or the force of some biological cycle pursuing its inevitable course, sweep it on. Just as the law of increasing size led the ancient reptiles to extinction, so these other laws can lead the parasite to self-destruction from which nothing has the power to save it, except a like reasonless reaction of its host against it, or the conflict of the demands of other organisms with its own, or, latterly, what is a special instance of the same thing, the interference of man for his own ends.

CHAPTER IX

CONCLUSION

The foregoing pages may have made clear the fact that if we wish to control or eliminate those animals which attack our bodies, damage our crops and domesticated animals, render unfit for consumption our stores of both animal and vegetable food, or destroy our clothes and fabrics and other manufactures, we must try to understand their whole life histories, so that we may strike at the weakest point in them. We can only do this if we study other animals as well as parasites, and we shall often find that the young stage of the parasite is the most vulnerable and that a "massacre of the innocents" is our cheapest or our only policy.

There will always be people who will object to any measure of this kind, for the simple if indefensible reason that they cannot approve of the destruction of any kind of life; and others, too, whose laziness or carelessness or lack of a sense of public duty leads them to shut their eyes to the miseries and hurt caused by parasites to man and other animals. The health of the public, the privilege of man to aid Nature in the task of creating and maintaining sane spirits in sound and vigorous bodies throughout the world—these are nothing to them. Others still, more subtle in their reasoning, may loose ironic shafts at the man who naïvely says: "This creature harms us, *therefore* we must exterminate it"; or, "This creature does us good, *therefore* we must foster it by every means in our power." For to argue so, they no doubt rightly point out, is to yield to the voice of the age-old instinct of self-preservation, and we ought by now to have conquered such primitive urges.

Yet the clever sophist can maintain with just as

much plausibility that most of the so-called "higher" ideals that modern man is supposed to have set up in place of the ancient gods of sex, hunger, and fear, are little more than tinsel we like to make for the decoration of our habitual garment of self-esteem. Our Truth, our Beauty, our Goodness and Benevolence, what permanence have they? If there come upon us a war or a famine, an epidemic of disease that decimates the human population, or any other catastrophe that wakens to action that terrible lion the primitive urge towards the preservation and propagation of the species, where are the altruistic virtues then? Brute force, blood lust, the ruthless destruction of all that harms or can harm us—these are our virtues when we are gripped by race fear. How, then, can we count ourselves "higher" or better than the tapeworm? That creature steals its host's food and selfishly strives, at the bidding of what we call Nature, to come to a working arrangement with its host. Are we its superior when we exterminate rats, or massacre mosquitoes wholesale, or gravely regret that we know no way of wiping out all the wild game of Africa because in their blood there lives, without harm to any but ourselves and the animals we wish to utilise, a tiny trypanosome that kills our best beloved?

We have a thing called a brain, that is all the difference. It gives us enormous advantage over other animals; it gives us choice also, which is denied to the parasite; and of that power of choice is born another self whose voice reproaches us when we wilfully kill and notice that the parasite cannot choose but to do harm. To still this uncomfortable voice we say, "Well, we are but human," meaning, though we know it not as a rule, that we are but animals still and must preserve ourselves as the tapeworm must.

Heart-searchings such as these are not, however, within the province of the practical biologist. If anyone shall ask him to tell how to control any animal

scourge, it is his duty, whatever his personal religion or philosophy, to give of his knowledge in a practical form; and no biologist will be slow to do this. The only lack is an adequate realisation by those in high places that biologists can be of real service to the community. There are signs that this serious defect is being remedied. We may hope that a competent biologist will be given both the position and the power demanded by his capacity to help all kinds of health worker, farmer, and educationist, to mention only three of the fields in which he can be useful. But for how long must we wait until this obviously necessary measure is taken?

It would be interesting, had we the further space, to consider several other lessons that the study of the parasite can teach us. They are lessons that are also taught by the study of any branch of biology; but parasitology especially brings home to us the need to avoid at all costs, if we wish to understand the animals aright, the prejudices that our human outlook is apt to create. When we study parasites we must guard, for example, against the human abhorrence of the principle of conduct implied by parasitism. We naturally dislike the human "hanger-on" or the man who "sponges" on others; and this dislike may blind us to other qualities he may have. It is not very difficult to carry this prejudice into the study of the animal parasites and to forget that our business is not to judge it by human ethical standards, but to see it dispassionately in the cold crucible of logic and to try to understand it as an intricate whole in relation to an intricate environment. To do this we must try to put ourselves in its place as far as we can, make an effort of imagination as well as of analysis and keep ourselves out of the picture. This is, in essence, what the great artist does when he studies the human material that he uses, and the attempt to do it must make us, not only better biologists, but also better men.

We must guard, too, against the human instinct to misunderstand the ugly. Great artists, great writers, men who are swayed by a sweet and revealing genius of pity, have overcome this prejudice against the ugly and have given it its due. But can even they without effort regard the tapeworm without loathing?

This means, if we look closely into it, that we feel, whatever we may be thinking, that the parasite is not only ethically ugly, but that its structure also violates our sense of beauty. Yet if that is the view of most people when a mass of lice in the hair of a child is being looked at, what is their view when they see a louse through a microscope and do not know what it is? Is it really the parasite that we feel to be ugly, or does its ugliness spring from the feelings we associate with it?

This is the same problem as the common prejudice against the painting or the description in words of, say, unpleasant industrial or slum conditions of life or the uglier passions. Yet it needs but a painter or writer of sufficient art, and we see a great beauty in what before was ugly. The microscope or the laboratory technician can perform the same office for us, and can do it without the artist's necessity of selection. They alter nothing, suppress no fact, but merely present the parasite as an animal stripped of its human associations; and behold! a liver fluke is a marvel of beautiful structure, a trypanosome a miracle of lovely sinuous movement in a drop of blood, and even a scab mite a thing of considerable beauty.

The parasite, therefore, is a living arbiter in the perennial struggle over that ancient bone: Is beauty in the object or in the observer? It proves the latter view to be right; or at least it works in favour of Alexander's view that "even natural beauty is a fusion of the object with the observing mind." For there can be no proper appreciation of the whole content of beauty in any object without a full knowledge and under-

standing of that object. When I see a tapeworm for the first time I may hesitate to call it beautiful; but the parasitologist who approaches it with imaginative sympathy, and has his wide knowledge of animals in general by which to judge it, may see that it has a beauty in its own category.

He will see, moreover, that, apart from the element of mere structural beauty in it, there is in every parasite a subtler beauty which only knowledge can reveal. Parasites, no less than other living things, are marvels of adaptation to the surroundings in which they have to live; if they were not they would not be able to live. Their slow evolution throughout the ages is a wonder awaiting whatever artist shall think he has the power to depict it; their fertility, the feats of food-getting that they perform, their incessant battle against heavy odds for the vital oxygen, and their struggle against innumerable forces that combine to destroy their young and do not cease their antagonism when those young that survive have grown to maturity; all these have the beauty that the human mind attaches to all things that invite, or even force, its admiration, or tickle its sense of romance, or show it, even in the life-struggles of creatures that it instinctively abhors, clear evidence of the existence of that guiding power which some call "élan vitale," or "nature," or "entelechy," or any other evasive name; but which some contentedly and frankly recognise as the spirit of God.

The conclusion, therefore, must be that whatever the angle from which we see the parasite, whether we be priests or artists or scientific observers, we cannot say that it is wholly false or ugly or evil. Our enemy it may be often enough; the enemy of all that lives, no less; but it is of our blood and our ancestry and kindred, and we can, if we will but honestly try to understand it, see in it grains at least of the truth, the beauty, and the goodness that are never absent from any constituent of our universe.

BIBLIOGRAPHY

1. Alexander, S.: *Art and the Material.* (Manchester University Press.)
2. Balfour Browne, F.: *Insects.* (Benn's Sixpenny Library, No. 45.)
3. Brumpt, E.: *Précis de Parasitologie.* (Masson et Cie, Paris.)
4. Calman, W. T.: *Crustacea,* in Part VII. of *A Treatise on Zoology,* edited by Sir Ray Lankester. (A. and C. Black.)
5. Cameron, T. W. M.: *Parasites,* in *Black's Veterinary Dictionary.* (A. and C. Black.)
6. Dakin, W. J.: *An Introduction to Biology.* (Benn's Sixpenny Library, No. 117.)
7. Dobell, C. C., and O'Connor: *The Intestinal Protozoa of Man.* (John Bale, Sons, and Danielsson.)
8. Esdaile, Philippa C.: *Economic Biology,* Part I. (University of London Press.)
9. Fantham, H. B., Stephens, J. W. W., and Theobald, F. V.: *The Animal Parasites of Man.* (John Bale, Sons, and Danielsson.)
10. Fiebiger, J.: *Tierische Parasiten.* (Urban und Schwarzenberg, Berlin und Wien.)
11. Guénaux, G.: *Entomologie et Parasitologie Agricoles.* (J. B. Baillière et Fils, Paris.)
12. Imms, A. D.: *Textbook of Entomology.* (Methuen and Co.)

13. Kaupp, B. F.: *Animal Parasites and Parasitic Diseases.* (Baillière, Tindall and Cox.)

14. Kaupp, B. F.: *Poultry Diseases.* (Baillière, Tindal and Cox.)

15. Leiper, R. T.: *Some Inhabitants of Man and Their Migrations, in Animal Life and Human Progress,* edited by Arthur Dendy. (Constable and Co.)

16. Lull, R. S.: *Organic Evolution.* (Macmillan and Co.)

17. Macfie, R.: *The Body.* (Benn's Sixpenny Library, No. 141.)

18. Mangham, S.: *An Introduction to Botany.* (Benn's Sixpenny Library, No. 118.)

19. Marotel, G.: *Parasitologie Vétérinaire.* (J. B. Baillière et Fils, Paris.)

20. Ministry of Agriculture and Fisheries, Sectional Volumes: No. 2, *Insect Pests of Fruit Trees;* No. 5, *Diseases of Animals;* No. 11, *Insect Pests of Farm and Garden Crops.*

21. Neveu-Lemaire: *Parasitologie des Animaux Domestiques.* (J. Lamarre et Cie, Paris.)

22. Pearl, R., Surface, F. M., and Curtis, M. R.: *Diseases of Poultry.* (Macmillan and Co.)

23. Russell, E. S.: *The Study of Living Things.* (Methuen and Co., London.)

24. Stitt, E. R.: *Practical Bacteriology, Bloodwork, and Parasitology.* (H. K. Lewis and Co.)

25. Theobald, F. V.: *A Textbook of Agricultural Zoology.* (W. Blackwood and Sons.)

26. Walton, C. L., and Wright, W. R.: *Agricultural Parasitology.* (Sidgwick and Jackson.)

27. Ward, A. R., and Gallagher, B. A.: *Diseases of Domesticated Birds.* (Macmillan and Co.)

28. Wardle, R. A.: *The Principles of Applied Zoology.* (Longmans, Green and Co.)
Contains a very full bibliography.

29. Wenyon, C. M.: *Protozoology.* (Baillière, Tindall and Cox.)

30. Woodger, J. H.: *Elementary Morphology and Physiology for Medical Students.* (Oxford University Press.)

Those who have no training in biology are especially recommended to read Nos. 2, 5, 6, 8, 15, 16, 17, 18, 20, and 30.